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# ON FLOOD HEIGHTS IN THE MISSISSIPPI RIVER, WITH ESPECIAL REFERENCE TO THE REACH BETWEEN HELENA AND VICKSBURG.

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In considering the question of high-water heights, it is evident that the best prospect of success lies in the study of the discharges already measured.* There are quite a number of data of this kind from the days of Humphreys and Abbot to the present, but of these only a few are of any material service in our investigation. By far the most useful and most accurately determined measurements of this kind are those made in 1882 and in 1884–85 by the Mississippi River Commission, and published in their Reports for 1883 and 1887 respectively. The former are especially valuable, having been made in the greatest flood-year ever known. Accordingly it is upon them that the reasoning of this paper mainly rests.

Since about 1872, daily observations of the stage of the Mississippi and its principal tributaries have been made at a considerable number of

* To avoid repetition, reference is here made to a paper published in the Transactions of the American Society of Civil Engineers, Vol. XX, page 85; March, 1889, entitled "The Improvement of the Mississippi River."

stations, the principal of which are Pittsburgh, Cincinnati, Chattanooga, Nashville, Dubuque, Keokuk, Leavenworth, St. Louis, Cairo, Memphis, Helena, Little Rock, Vicksburg, Shreveport and New Orleans. At these and many other points gauges are established, the zeros of which are arbitrarily fixed, but are usually intended to be at about extreme low-water mark. In a few instances, subsequently to the establishment of the gauges, the water, in a very low season, has dropped below the zero.* It is to these gauges that all the discharge observations made since 1872 are referred.

If we take a sheet of cross-section paper and plot the days of the year as abscissas and the gauge readings at any given station as ordinates, we shall have a curve showing the movement of the river for that year. Such a curve is shown on Plate XL, and is called the hydrograph of that station for such or such a time. If, now, we take the discharge observations at this station, and, still making the gauge readings the ordinates, plot the discharges or their components, the areas and mean velocities, as abscissas, we shall have a series of lines usually called the discharge curve, the velocity curve or the area curve of that station for that year.† If, now, we make the time the abscissa, and the discharge, velocity, area, mean depth, slope or other function the ordinate, we shall have a series of broken lines to which Colonel Suter ‡ has given the name sequence of discharge, velocity, etc.

Now, if there be any definite relation between gauge and discharge, it should make itself recognizable in the shape of the curve constructed from these elements as co-ordinates.

Unfortunately for our hopes, the line which thus results is exceedingly complex, and apparently lawless in its shape, which is a zig-zag, not reducible to any regular curve, or rather which may be fitted to almost any curve, at the fancy of the investigator. Of course, it is well known that there are numerous sources of error in discharge measurements, and a portion of the apparent anomalies may rationally be attributed to this cause. In order to disembarrass the subject as much as possible of accidental errors, let us consider, not the discharge, which is composed of two factors, but only one of these factors, the velocity,

* As at Vicksburg in 1888.

† See these curves plotted, for 1882, in the plates accompanying the Report of the Mississippi River Commission for 1883.

‡ In a paper laid before the Mississippi River Commission in 1888, in the "Investigation of Discharge Measurements." Mississippi River Commission print, 1888.

In this way we may partially eliminate the errors of measurement of the areas, which are well known to be sometimes considerable. We cannot entirely eliminate those errors, on account of the manner in which the mean velocities are obtained, namely, by the summation of the partial discharges and then division by the sum of the partial areas. Under only one condition can the errors disappear entirely, and that is, that the partial areas shall be equal, and the errors of measurement of those areas equal also. Otherwise, an area in excess will give a velocity in deficiency, and *vice versa*. Still the errors will be partially compensated. Moreover, the velocity is the controlling element. If there be any law regulating the discharge, as who doubts that there is, it must be sought in the velocity.

While there are inaccuracies, as developed by plotting, which are justly ascribable to faults of observation, there are variations which, from their magnitude and their persistency, must be attributed to other causes. Among other things, there seems to be a break in the velocity curve at the "bank-full" stage. Beyond this point it becomes wild, sometimes showing no increase or even a diminution for several feet of rise, sometimes developing such a prodigious augmentation as to give an addition of 200 000 feet or more of discharge for a foot more on the gauge. These are not irregularities or eccentricities. The Mississippi is not an anomalous creation, but on the contrary, is beautifully amenable to law, and obeys it with minute and unvarying fidelity.

It is well known that velocity depends principally on volume, slope and conformation of cross-section. The first of these is generally recognized as by far the most powerful ingredient. The explanation of its predominant influence has often been given. It depends on the fact that the resistance of friction increases in proportion to the perimeter, and that the area increases in a much greater ratio. Of course, friction is the principal obstacle to free flow, and by it the water is prevented from acquiring a velocity indefinitely great. In proportion, then, as this obstacle is lessened, is the velocity subject to increase.

It is evident, however, that volume does not, of itself, absolutely control velocity, or the correspondence between them would be close, and the velocity curve regular, and free from the perturbations above noticed. In seeking the causes of these perturbations, our attention is naturally first directed to the slope. Let us, then, plot the slope of two or more adjoining stations. Let the Helena observations of 1882 be the first

example.* Let the velocities be plotted to time, forming what has been called a sequence of velocity, and compared with the slope from Mhoon's (30.2 miles above) to Helena, and from Helena to Malone's, 49.7 miles below.† The slope is most conveniently expressed in decimals of a foot per mile. (See Plate XL.) With the slope above there appears to be little connection, but the correspondences with the slope below are very noticeable. They are not minute;‡ but considering the nature of the data they are striking, and suffice to explain some of the apparent anomalies in the line of velocities. Hence it is evident that while stage is an important element of discharge, as connected with volume and with those various factors which enter into the velocity formula, yet it is not absolutely controlling, much less has it any definite relation to discharge, being often itself controlled by slope. In other words, we frequently find that a greater discharge will pass at 46 feet of the gauge, than at 47 feet, and when this is the case, we generally find that the slope has been steepened in the former case or flattened in the latter. Not always, however. There are other elements which go to form the velocity. The chief of these is the mean depth, which represents to some extent both volume and conformation. This element is given approximately in the different discharge observations. Let, then, the mean depths be plotted. Now, there are some other discrepancies which disappear.

For another example, let the Arkansas City observations of 1884–85 be taken.§ For the determination of the slopes we have the mouth of White River, 45.1 miles above, and Greenville, 40.2 miles below, with which to compare it.‖ (See Plate XLI.) As there was no great flood this year, there was no escape from the channel of any consequence, and, as might have been expected, the correspondences are closer, though still for the most part confined to the slope below. Unfortunately, we have no discharge observations at Arkansas City during a very high water, except the

* Report of the Chief of Engineers for 1884, page 2619.

† It is not maintained that these distant stations afford any accurate criterion by which to judge of the effects of slope. At best, they can only be regarded as evidence of changes of slope taking place at those times. They are the only testimony we have, and we must make the best of them. The readings from which these slopes were obtained are printed in a pamphlet entitled "Stages of the Mississippi River from Cairo to Carrollton." Mississippi River Commission Print, 1888.

‡ In plotting these slopes, no time allowance has been made the date referring to stage at Helena. Had a time allowance been made, the effect on the lower of the slopes would have been to advance them the greater part of a day, and make the coincidences generally closer.

§ Report of the Chief of Engineers for 1887, Part IV, page 2838.

‖ Stages of the Mississippi River from Cairo to Carrollton.

isolated observation of 1887, which is, however, of great value. But we have the gauge records of several years. From these we perceive that there is an important difference between this case and that of Helena, namely, that the slope is much less, being only 0.37 as against 0.45. We also perceive a point of resemblance, namely, that the slope increases with the stage.

It is evident that the latter phenomenon is purely local. It is well known that the high-water and low-water slopes of the river as a whole are nearly the same. From Helena to Arkansas City there is only a difference of 0.01 between them, and from Arkansas City to Vicksburg the low-water slope is the greater by 0.03. Therefore there must be a point between Helena and Arkansas City and another between Arkansas City and Vicksburg where the reverse process takes place, and the slope diminishes as the gauge height increases.

To endeavor to arrive at a clear idea of the laws that govern the slope, let the high water profiles be plotted of such years as are accessible to us and have any special significance. 1882, 1883 and 1884 were very much alike in most respects, and one of them will suffice—1882—as being the greatest and presenting the most complete data. In 1886, the levees on the Mississippi side were complete, with the exception of two or three breaks of no particular importance. In 1887, the Arkansas levees were finished above Arkansas City, and as far down as Gaines' Landing. In 1888, for the first time, the river was entirely confined by levees on both sides from Arkansas City to Vicksburg. In 1885, the river, for all practical purposes, was within its banks the whole year. Let these suffice on the one hand, and the low water slopes of 1882 and 1883, as presenting the most and the best determined data, on the other.* (See Plates XLII, XLIII and XLIV.)

We now perceive that the peculiarities alluded to a little while ago were merely particular instances of general laws. Had the examination been carried a little farther, it would have been found that at Red River Landing a velocity of 6.8 was attained at a slope of 0.24, and that at Carrollton a velocity of 6.16 corresponded to a slope of 0.13.† It is evident, then, that slope and velocity have not a precisely defined relation, though there is an intimate connection between them. A given slope

* The data for 1882, 1883 and 1884 are given in the report of the Mississippi River Commission for 1885. The data for 1886, 1887 and 1888 are given in the reports for those years.

† Report for 1883.

does not by any means necessarily correspond to a given velocity; nor does bringing the mean depths into the matter help us to an explanation. The formula which at one time requires a co-efficient of 83, at another requires 150. In fact, with equal velocities the high water slope diminishes gradually from the head of the alluvial basin to the Gulf, and this general curve is broken into numerous subordinate curves of more or less irregular figure. In considering these, we must remember that they were formed under disturbing circumstances. In only one of the instances under discussion was the river confined approximately within its banks, and that year succeeded three great flood years, and its slope partook of the irregularities of the bed which they had transmitted to it. Part of the broken appearance of the curve is therefore undoubtedly due to differences of cross-section and volume. None of the irregularities are without a reason; and if they are not always explainable, it is only because our knowledge is not sufficiently extensive or accurate.

By the conditions of its existence, the velocity of the river is nearly constant throughout its whole course, being that which is compatible with the stability of its banks. It is not absolutely constant, but suffers perpetual oscillations.

The statement that under the condition of a constant velocity the slope becomes progressively less is one of great significance. So far as I know, the true explanation of it was first suggested by Mr. Eads,* who attributed it to the acceleration consequent on the long fall. The correctness of this explanation is quite apparent. If the bed of the river were an inclined plane, the form of the water surface would be a parabola, modified, it is true, by friction, but still preserving the property of an increasing velocity and a diminishing cross-section as the fall progressed. It is a matter of common remark that a ditch or trough having a fixed inclination cannot be made to run full at its lower end, no matter how much water be poured into its upper end. Therefore, in order that the velocity may remain constant, the bed must be a curve and the surface a parallel curve, the shape of which has not yet been determined. The water surface which forms this curve is that of mean floods, not of moderate or low stages, nor of excessive floods. The one follows too closely the shape of the bed—that is, it is controlled by the

* In his testimony before the Burrows Committee, page 425. I am not aware that he pursued the idea any further.

shoals and irregularities of that bed—and the other is generally of too short duration to have a permanent formative influence. The measure of this mean flood is the bank-full stage, as it has been shown* that the banks are built up to this stage and no higher. Floods less than this stage, then, conform more or less closely to the low water slope, and higher floods do not preserve a constant velocity, but suffer acceleration.

The small oscillations to which reference has been made occur periodically in bends. In every concave bend the velocity meets with a check from its abrupt contact with the bank, unloads its burden of sediment on the crossing and reaches its minimum of velocity and of slope on the shoal—thence to descend with a slope steeper at first, but becoming flatter as the velocity is accelerated by the fall, until at the next concavity the process is repeated.

These oscillations are not represented on the plot, owing to the insufficiency of the data; nor is it necessary that they should be, as their influence is inconsiderable on the large scale. But the great irregularities are of grave import, and it is essential that their causes should be understood. It might at first be supposed that they arise simply from the abstraction of large masses of water by escape over the banks, thus lowering the surface as by a waste-weir. Many of the great depressions admit of this explanation, but not all; for some of the most striking peculiarities are as conspicuous, though not of so great magnitude, at low water as at high. Some are plausibly explained by the effect of recent cut-offs, or by the escape of large volumes across the necks of points; others are principally or wholly attributable to deterioration of channel caused by crevasses or escapes over the banks during great floods. When it is said that the high water slope is formed by mean floods, it is on the tacit supposition that the flow continues uniform. If it be not uniform, then great disturbances of cross-section and volume, maintained throughout a considerable and prolonged flood, will produce changes in the bed that will influence the high water slope materially and for a long time, until removed. The effect of the application of this theory to the line of slopes is exactly opposite to that of supposing the water line lowered by waste-weirs. The hollows in the line will now represent the places of least escape, and the bumps the places of greatest loss.

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* See on this subject a paper by Professor Mitchell, in the report of the Mississippi River Commission for 1882, page 264.

The deterioration of a channel is mainly due to two causes. One is the disturbance of velocity due to the lateral movement of the water as it escapes over the banks or through crevasses; and the other is the diminution of velocity arising from loss of flowing volume. It is not admitted by all engineers that the former agency has any important effect. It is stated by Humphreys and Abbot * that no crevasse, great or small, has any perceptible influence upon the thread of the current more than 200 or 300 feet from the bank. It would appear that it must produce some perturbations of the velocity, sensitive as it is. Whether it does or not, none can deny the effect of abstracting a large fraction of the contents of a river for a considerable time. The amount of sediment brought down by the Mississippi at flood height is much less at its surface than the mean.† Consequently, the water that escapes over the banks lessens the volume without proportionally lessening the burden. Hence, a deposit of sediment and a contraction of the cross-section. Moreover, were the proportion of sediment the same after the loss as before, the resistance of friction becomes greater as the volume diminishes—hence a diminution of velocity and a fill. The result is summed up by, I think, Captain Leach, in the observation that a river will not tolerate a bed that is too large for it. Therefore, supposing a river, through confinement by levees, to have at one part of its course a mean high water discharge of 1 200 000, and at another, through a break in the levee, of only 1 000 000—yet, if this condition be permanent it will remain bank-full in the latter as well as in the former case, in spite of the escape through the outlet; and if the break be closed, it will rise to an additional height below the closure, and will flatten the slope for the time being, for a considerable distance above.

The doctrine of stage and slope, then, may be thus stated: All other circumstances being the same, there is a definite relation between stage and velocity, and the higher the stage, the greater the velocity. But with a change of circumstances, especially in the matter of slope, there is no definite relation between stage and velocity. So likewise, when there is a velocity which corresponds to a given slope and stage at a

* Pages 283 and 284.

† See Humphreys and Abbot, page 134, and the elaborate current and sediment observations, especially at St. Louis, made in 1880-81. Report of Mississippi River Commission for 1882, pages 116-155.

given place, then any increase or diminution of the slope is accompanied by a corresponding change in the velocity.*

There are yet two principal causes of some of the irregularities in the flood line, and these are the influence of the great basins, acting as reservoirs, and the contributions of tributaries—the two being frequently combined. As these are matters of the highest importance, it is proper that they should be thoroughly discussed.

The effects of reservoirs on so great a scale and under such varying circumstances are very complicated, and it will conduce to a clearer understanding of them to consider first some simpler types, to one or another of which the actual cases more or less approximate. Suppose, then, a river to be divided for a certain distance into two branches, which are reunited below, as in the case of an island in the Mississippi. The water proceeds down the two channels, each of which has its appropriate discharge, great or small, and they mingle at the point of union with little or no disturbance. Consider now the case of a river which expands into a lake, with ample depth and unobstructed, and then issues from the lake by a passage contracted to its former dimensions. So long as the discharge is regular, as much water leaves the lake as enters it. The fall over the whole reach is mainly concentrated at the head of the lake, and the greater cross-section is compensated by a diminished velocity. Now, suddenly let a freshet pour an enormous volume into the upper part of the lake. By virtue of its favorable cross-section, this volume will be rapidly transferred from the upper to the lower part of the lake, and an engorgement will ensue, until the increased height permits the passage of the increased discharge. The height thus reached will be greater than would have been reached in a stream of uniform cross-section, and will occur earlier.

Take now the case where the lake, instead of being deep and unobstructed, is shallow and full of trees and undergrowth. A freshet is impeded in its progress, raises the water at the upper part of the lake, and acquires sufficient velocity to pass the discharge. It consumes

* This assertion is strictly applicable only to such places as are origins of velocity; that is, where the velocity, having received a check from one cause or another, takes a fresh start toward acceleration. In other situations, the velocity may not correspond with slope at all, but be governed by the momentum already acquired, as has been acutely observed by Captain Leach, in his observations on the Carrollton observations of 1879, where there was actually in some instances a reverse slope (the river running up hill) for considerable distances. See Report of Mississippi River Commission for 1882, page 103; see also the low-water observations of 1883, in the Report of the Mississippi River Commission for 1885.

time in this effort, and arrives at the lower end of the lake behind the regular period. The flood line at this point is at first lower than it would have been in a confined stream, but it does not afterwards materially exceed the normal height.

Suppose, instead of a lake which is part of the stream, a great empty reservoir, access to which is given by breaches in the banks or levees which confine the main river. The surface of the river will be lowered and stay lowered as long as the discharge into the reservoir progresses uniformly with the increase of flood discharge of the river. After the reservoir is filled, it will receive water at the upper end and discharge it at the lower. It is obvious that the effect upon the height of the stream at and below the lower end of the reservoir will depend upon the time and manner of return, and this will depend upon which of the three types above mentioned the reservoir most resembles. It actually partakes of the nature of all three. At first the flow is over shallow and obstructed ground, then is concentrated into water-courses becoming deeper and deeper, and at the foot of the basin it approximates to an unobstructed lake. If the contents of the reservoir can be held back until the body of the flood has passed, the flood-line will be lower than in a uniform stream. This, however, can hardly be the case when the reservoir cannot be artificially closed, the water being free to follow the impulse of gravity, and with a greater fall than in the river. If it be poured in on top of the flood, it may be higher, for this reason. If there were no crevasse or outlet, but the river were confined between banks, it would be doing its full duty. While the crevasse or outlet (presumably in the upper part of the basin) is open and the surface of the main stream lowered, then the river is not doing its full duty. Now suddenly return the water lately abstracted through a channel at the lower end of the reservoir, while the flood is at its height. As the river has been lately doing less than its duty, so now it will have to do more, and the surface will be raised accordingly until it can pass the discharge. Now what are the facts? At Cairo, in 1882,* the top of the rise of February was not past but within 0.6 of its full height on the 4th of that month. The outflow from the St. Francis was in full progress on the 7th, and reached its height on the 13th. The second rise was within 0.2 of its crest on February 26th. The return swell at Helena began on the 3d of March, and was at its height from the 6th to the 10th. The

* Stages of the Mississippi River from Cairo to Carrollton.

flood wave of 1883 was very strongly marked.* It stood at 52.08 at Cairo on the 28th of February. The outflow from the St. Francis began about the 2d of March and reached its maximum on the 8th. Now a flood wave should take about three days to pass from Cairo to Helena. It is clear, then, that the return flow catches the flood. Another proof of this is that the river in all these instances had not fairly begun to fall at Memphis when the return wave overtook it at Helena.

This proof is not conclusive, because it does not show that the water which was abstracted from above was returned suddenly enough to meet the conditions of the hypothesis. It would appear from the movement of the gauge at Helena, that its return was sudden—for the river had very nearly reached a stand in each case, showing that little, if any, had returned before the great swell. After the swell had passed, however, there was still a large mass that returned more slowly. At Helena, on the 15th of March, 1882, the quantity that was returning was estimated at about 475 000 feet per second, the river being then on the decline. Two weeks afterward, the gauge still stood within 2.5 of high water; and the stream was not fairly within its banks till nearly the middle of April; so it cannot be denied that a considerable portion of the return flow follows after the crest of the rise. Let us see what can be learned from the discharge and crevasse measurements.† At Hampton, 12 miles below Memphis, the maximum discharge was estimated at 1 210 000 feet. Maximum return flow from Memphis to Helena, including the discharge of the St. Francis River, 548 639. Escape into the Yazoo Basin above Helena, 268 795. Net estimated discharge at Helena, 1 490 639. Actual measured discharge, 1 562 240.‡ Now what should have been the maximum discharge had the St. Francis Basin been closed (leaving open the foot, of course, for drainage)? There passed Columbus about 1 746 000 feet, of which nearly all was in the channel and actually measured. The discharge of the St. Francis River was estimated at 52 000, but was evidently much greater. The observations of 1883, taken under very similar circumstances, place it at a much higher figure. It may easily have been as much as 80 000. Adopting, however, the estimate first given, and deducting 268 795, as before, for

* See the hydrograph of this flood, in the paper on the Improvement of the Mississippi River. Transactions, Vol. XX, March, 1889. Plate XIV.

† Report of the Mississippi River Commission for 1884.

‡ Discharge observations at Helena in 1882, in the report of the Mississippi River Commission for 1883.

escape into the Yazoo Bottom, we have about 1 530 000 as the probable net discharge at Helena. The difference between this and the actual discharge is so small that it may well be regarded as within the limits of error. So far, then, both reason and experience seem to point to the conclusion that the closure of the St. Francis Basin would not have any very marked effect either in increasing or diminishing the maximum discharge at Helena. How, now, as to the flood height?

It is not only the quantity of water but the manner of its return that has to be considered. It was abstracted from the river in such a manner that it probably had an effect more or less decided in diminishing the velocity. It is now thrust back into the channel a mere mass of brute water, in a direction approximately perpendicular to the thread of the current. Were it returned in a direction parallel to the current, by the laws of collision the velocity of the united mass would be equal to their combined momenta divided by the sum of their masses. As it is, the velocity of the returning flood water, great or small, makes no difference, for its effect is null by its direction. But even were its direction favorable, the velocity does not exceed one foot per second.* It may easily be understood what its deadening effect must be. To 1 200 000 cubic feet of water moving with a velocity of 5.4 per second, add 300 000 with a velocity of zero, or even one foot. The resultant velocity will be 4.5. It is not proposed to use this method quantitatively, in ascertaining the additional elevation that must thus be given at Helena, to communicate the observed velocity of 6.7. The data are too crude for such a purpose. Moreover, the flow was not all projected in one body, nor at Helena itself, but in all quantities, at various points in the vicinity of the mouth of the St. Francis River. Still the principle is rigorously accurate, as is apparent to any one. The water of the stream has its own duty to perform, in transporting its weight against the resistance of friction. Give it an additional quantity, moving with the same velocity, and its task is not increased. But impose upon it a burden, in the shape of an inert mass suddenly thrust upon it, and its labor will be increased and its velocity lessened. It may be said that the returned water will acquire its own velocity. So it will, in time. In the meantime it is swelling the river to a height beyond that which it would have attained had it never been withdrawn. Therefore, while it is very possible that

* See the observations of 1882 and 1883, in the Report of the Mississippi River Commission for 1884.

the discharge of 1 560 000 would have taken place whether the St. Francis Basin had been closed or not, it is certain that the gauge height at Helena was higher than it would have been in that event.

It is to be remarked that this reasoning applies only to great floods. In small floods, the movement of the overflow water is necessarily slow and impeded. It takes a long time to fill the reservoir, and a long time to empty it. The proportion of water permanently retained in the lakes and depressions of the reservoir—such as the sunken lands of the St. Francis Basin—is relatively large, compared with the whole. In fact, there may be overflow enough to fill the basin and no more. Therefore, in such a case, a reservoir may be positively beneficial. Unfortunately in small floods this beneficial influence is of no great moment.

We now see why it was that the velocity at Helena and Arkansas City was so little affected by the slope as compared with stations above, as Mhoon's and the mouth of White River. Between those stations and the principal points there was interposed the disturbing influence of the volume of returning water from the swamp and tributary. Had we chosen a station like Hays' Landing, we would have found that the velocity at high water sympathized with the slope as compared from above rather than with that from below, because this time the disturbing influence is on the lower side, between Hays' and Vicksburg (see Plate XLV), and compare the slope Greenville-Hays' (unfortunately defective) with the slope Hays'-Vicksburg. The slope Lake Providence-Hays' (not plotted on the plate) corresponds closely to the slope Hays'-Vicksburg, showing that the velocity at Hays' is affected more by momentum than by slope. The change really occurs about Ashton.

The data for the Yazoo Basin are much less satisfactory than for the St. Francis. We lack the important advantage of places like Columbus at the head of the basin and Helena at the foot, where the discharges were measured. Furthermore, the phenomena along that front were greatly complicated by the large escape over the Tensas front, directly opposite. The method of reasoning, however, is exactly the same. The case of the Yazoo Basin is stronger on account of its perfect system of drainage, and the greater quantity of clear and unobstructed waterway.

The entrance of tributaries into the main stream is governed by the same laws. If the angle of impact be favorable and the velocities of the two streams equal, the flood wave resulting will be of uniform height—

that is, its crest will be parallel to the surface of the main stream so long as the supply continues unaltered. But if the velocities are unequal, then one or the other stream will contribute material faster than the resultant velocity will carry it off, and there will be a rise at the point of junction, "flattening out" as it proceeds down stream.

It is high-water conditions that now interest us, and at such times the entrance of the tributary waters into the Mississippi is always modified by discharge into an intermediate reservoir. As the Arkansas and White Rivers are the most important contributors to the flood waters of the Lower Mississippi, we will speak particularly of them. These streams interosculate near their mouths, and pour their discharge through two channels, but principally through the mouth of White River. It has been observed, many years ago,* that tributaries frequently manifest, at their mouths, the same tendency that the main stream does at its debouchement into the sea, namely, to form deltas. The cause is the same—the discharge into a stagnant basin—and the explanation is well known.

The White River Basin is an oblong area, of an average width of perhaps 13 or 14 miles, from the uplands of Arkansas on the one side to the Mississippi levees on the other, and about fifty miles long from its head, just below Helena, to the Cypress Creek line of levees, which is the beginning of the Arkansas and Louisiana system along the Tensas Front. The upper portion of the White River Front is protected by levees, and one or two limited areas are encircled by embankments built at private expense. This basin is filled by overflow from the Mississippi at high stages. Previously to the reconstruction of the line of levees along the bank of Cypress Creek (known as the Opossum Fork Levee) the lower end of the White River Basin was open and discharged directly into the Tensas Basin, pouring down a vast body of overflow, which has been variously estimated, but was always considered by the Louisiana people, whom it affected, as of great extent and consequence. In 1885 and 1886 the line just alluded to was rebuilt, but suffered numerous breaches in the latter year. In 1887 it was successfully held, and it is now both high and strong. Considered merely as a reservoir it might be thought that the influence of the White River Basin would be inappreciable on account of its compara-

* See a very interesting and able pamphlet by Colonel Albert Stein, on the Improvement of the Mississippi River, printed at Philadelphia in 1842, page 5.

tively small extent. It does not take long to fill it—and it might be supposed that the discharge of the main river would pass freely through the overflow as between banks of water. So doubtless it would were the swamp water absolutely stagnant. But this it is not. It keeps flowing from the main river at the upper part of the basin, and into the river at the lower part. Therefore a part of the work of the river is spent in overcoming the resistances thus intruded into the system. This effect should be perceptible in an increased elevation at Arkansas City and a slightly delayed high water at that point. These phenomena are usually so complicated with those arising from the inflow of the tributaries that it is not easy to verify such reasoning by the test of fact. It is tolerably certain that some effect is produced, but it is hard to say how much.

Now as to the effect of the tributary waters. Though the basin is full at high water time, and frequently "backs up" the tributary, yet the latter does not by any means lose its identity on this account, nor is its velocity merged in that of the lake-like expanse. In 1882, when the Mississippi was only a little past its extreme height, and the White and Arkansas Rivers were comparatively low, yet the current at the principal common mouth was 4 feet per second, and at the secondary mouth (that of the Arkansas) more than 2 feet.* No better illustration could be desired of the conservation of acquired velocity, maintaining itself against slope. What the high water velocities of these streams may be I do not know. The obliquity at which the White River meets the Mississippi, as shown by the maps, is apparently favorable, and the flood-line presents few indications of any prominence of waves at that point. In fact, White River is not a striking illustration of the rule commonly laid down that the oscillation at the mouths of tributaries is excessive, as compared with that at intermediate points. The reason of this no doubt is that in this situation the tributary presents itself at a favorable inclination, and little engorgement is produced; and its effects are separated from those of the reservoir—the latter being most prominent below. It is otherwise with the Arkansas. The return flow from the basin is discharged between the mouth of the latter river and Cypress Creek, just above Arkansas City.

Nevertheless the range between high and low water is still greater

* Report on the White River Front for 1882, in Report of Mississippi River Commission for 1884, page 76.

than at the intermediate points; and the rule as laid down is generally correct. A great part of this excessive oscillation is very justly attributed by the Mississippi River Commission to the depression of low water at the former localities.* At Helena I have noticed, as no doubt others have done, that the mean bed of the river, which at moderate stages is about on a level with the zero of the gauge, at low water is ten feet or so below it. This phenomenon is not of universal occurrence, though whether it is confined to the mouths of tributaries I cannot say. It seems, however, to characterize such situations. See Plate XLVI, which shows the difference between the mean depth and the gauge reading at Helena in 1882 and 1884-85, at Hays' Landing in 1882, at Arkansas City in 1884-85, and at Warrenton (just below Vicksburg) in 1884-85, thus giving the depression of the mean bottom beneath the zero of the gauge. This depression is probably caused by the scour from the discharge of the tributary, the effects of which are generally most conspicuous at low water.

But a considerable portion of the oscillation must be attributed to excess of height as well as of depth. The phenomenon known as the "flattening out" of flood waves is well recognized; and it occurs most frequently with waves from tributaries. It will not do to ascribe this to an absolute difference of discharge between the mouth of the tributary and the station below; that is, to say that the flood wave being short and sharp, and the layers thereof traveling with different velocities, a high water above for one day is equivalent to a lower water below for two days—for the same thing is observed for prolonged high stages, where the discharge is necessarily equalized for great distances. The true explanation unquestionably is the same as that given for the excessive elevation of the returning flood water at Helena; that is, that it is projected into the main stream with an unfavorable velocity and direction, and an engorgement must result until increased height gives the requisite velocity—which height will be less as the velocity becomes accelerated by the fall—and the higher and sharper the wave, the quicker and more decided the "flattening out."

It is probable that a great part of the excess in height here alluded to is due to the influence of the reservoir rather than of the tributary. The actions of the two are usually inextricably intermixed. It is

* See Report of the Mississippi River Commission for 1884, page 16.

certain that the largest tributaries—the White and Arkansas—show much less excess in height than the St. Francis and Yazoo—and this may rationally be attributed to the smallness of the White River Basin as compared to the others.

The attentive observer will not fail to remark that even at the time of its greatest upward oscillation, the flood-line at the mouth of White River is very little elevated.* In fact, leaving out minor variations, the slope Helena-White River is materially greater than the slope White River-Arkansas City. In the typical year 1887 these slopes were 0.37 and 0.30. These relations are altered by the conduct of the tributaries. Thus in the two rises of 1885, the slopes Helena-White River were respectively 0.35 and 0.33—the slopes White River-Arkansas City 0.30 and 0.32. This brings to our attention the fact formerly adverted to that *volume* exercises a most important influence on velocity—one difficult indeed to submit to calculation, but very potent notwithstanding. It was remarked long ago by the Italian engineers, who had to wrestle with the same problems as ourselves, that the introduction of affluents into a stream was followed by a flattening of the slope below the junction.† In spite of this adverse influence, the velocity goes on increasing. In 1885, at the height of the January rise, the greatest velocity at Helena was 4.96—at Arkansas City, 5.37. During the April-May rise, the velocities were probably about 4.7 and 5.4.

It must be remembered that points intermediate between tributaries are also places of small discharge, where the "waste-weir" system has had full play. It is not possible that flood heights should be excessive where there is perpetual escape over the banks and no return, as along the Tensas Front, and the deterioration of the channel acts in furtherance of the same end—so that in such places the flood height is lowered and the low-water mark raised—a process precisely the reverse of that which takes place at the mouths of tributaries.

It is hoped that the irregularities in the flood-line are sufficiently accounted for, and the laws which govern the movements of the flood-waters sufficiently discussed. We may now proceed to the practical question as to the flood heights to be expected in the future, under the changed conditions which have occurred since the epoch of the great floods, and such other changes as may be reasonably anticipated.

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* See Plates XLII and XLIII.

† See Frisi on Rivers and Torrents (English translation, page 115).

In the present paper it is not intended to go higher than Helena. An investigation of high-water heights above that point would require an accurate local knowledge, and may be undertaken by those better qualified.

While the closure of the St. Francis Front may be regarded as a certainty at some time in the future, it is not imminent. Whatever progress is made in that direction may be expected to effect a reduction in the high-water mark at Helena. But it is a matter of absolute uncertainty how great this progress may be. Therefore we cannot count upon it at all, and our reasoning must proceed as though the existing state were to be maintained.

In 1884–85 the closure of the Yazoo Front was completed. In 1886 there came a considerable flood, not so great as 1882, 1883 or 1884, but sufficient to fill the St. Francis Bottom to its full capacity. That year the Helena gauge attained a height of 48.1—0.9 higher than in 1882.

It is of great consequence to us to know the discharge in 1886, but unfortunately the data with which to determine it are very scanty. It was not measured anywhere.* The gauge at Cairo stood at 0.85 less than in 1882; at Columbus, 0.07 less;† at New Madrid, 0.85 less. The slight engorgement at Columbus indicates that the velocity was somewhat less than in 1882—else why so great a gauge-height for a less flood? By comparing the observation of March 4th, 1882, when the slope Cairo-Columbus was almost exactly the same,‡ and allowing for the increase in mean depth, a probable velocity is found of 7.91, and a discharge of 1 497 213.

In 1882, at the observation stage, when the Cairo gauge was 3.19 feet below the high water mark of 1886, the escape over the banks, which passed the latitude of Columbus, was estimated at 48 311—at the maximum stage it was 89 000—so for 1886 it may fairly be estimated at 78 000—or say, altogether, for the whole discharge past Columbus, at 1 575 000. This should nearly all have been concentrated and passed New Madrid in the channel, as against 1 746 000 in 1882—and the estimate seems to be reasonable. The discharge of the St. Francis, which appears to

* This was not the fault of the Mississippi River Commission, but was the result of the failure of appropriations by which the most valuable labors of that body were subjected to serious and long continued interruption.

† Mean of the Columbus and Belmont gauges.

‡ There is no station below with which to compare it. Even at New Madrid there is no daily record for 1882.

have been at a moderate stage,* may be placed at its mean of 31 000. Deduct 20 000 for the crevasse at Austin, and we will have 1 586 000 for the maximum discharge at Helena, and it is probably well within the truth. From the extreme rapidity with which it was poured down, and the still more rapid recession of the flood, it is probable that the reservoir rather increased the discharge than diminished it.

By examining carefully the reports of the measurements of the water-escape over the St. Francis Front in 1882 and 1883,† we may form a pretty correct idea of the movement of the waters both of the river and of the swamp. In both these years, we perceive a great flow from the river into the reservoir between New Madrid and Memphis, the latter place being regarded as about on the dividing line between inflow and outflow. The observations of 1883 are especially valuable, as they began at the time of high water at Cairo and accompanied the flood down the river, terminating with the exact time of high water, or the swell from the return flow, at Helena. In 1883, then, it appears that from Memphis to a mile or two above the mouth of the St. Francis River, the main stream and the reservoir formed, in effect, one continuous sheet of water, there being no return flow of any consequence, as is evident from the fact that at St. Francis Island there had been returned only some 32 000 feet of discharge since leaving Memphis. Vast quantities of water escaped over the banks in bends, only to return over the point into the bend below. By the time the vicinity of the St. Francis is reached, the basin is extremely narrow—only five or six miles wide—and the water is impounded there. As the river falls, the reservoir begins to empty itself higher up, and in 1882 (the examination being made a week after the maximum stage) there was found to be a considerable escape all the way from Memphis down.

It is not easy to reason satisfactorily from 1882 to 1886, as the circumstances of the two years were not at all similar. Between 1883 and 1886 the comparison is closer. We may reason, therefore, from 1882 to 1883, and from 1883 to 1886.

The great increase of discharge in the last foot and a half at Helena in 1882 ‡ (about 300 000 feet) was due to the steepness of the slope.

* The Wittsburg gauge was very high, but it cannot be depended on, as it was affected by the overflow water. White River, which runs parallel to the St. Francis, and is affected by similar conditions, stood on the 27th of April at 16 feet at Jacksonport.

† Report of the Mississippi River Commission for 1884.

‡ Report of Mississippi River Commission for 1883, and see the discharge curve as plotted in the plates accompanying that report.

This is not fairly represented by the slope Helena-Malone's, which was 0.43. The slope Helena-Delta (8 miles below) was 0.60, and Helena-Friar's Point (13 miles below) 0.53. On the other hand, the slope Trotter's Landing (3 miles above)-Helena was only 0.42. The mean slope Trotter's-Friar's Point was 0.51.*

These irregularities are partly due to several crevasses in the vicinity of Helena, and in the immediate neighborhood of the places just mentioned. Partly also they are due to the stage and the circumstances.

In 1886 these gaps had been closed, and the slope Helena-Friar's Point was 0.48 instead of 0.53. On the other hand, the slope Trotter's-Helena was steepened to 0.73. From Trotter's to Friar's Point the slope was a trifle steeper than in 1882, being 0.52.† Above Trotter's, 1886 was higher than 1882, in a diminishing ratio as we ascend, until Austin is reached, after which it is lower. These circumstances would seem to indicate that the engorgement began higher up in 1882, that its wave was flatter, its crest lower down and of less altitude. These circumstances partially offset one another so that on the whole, even with a greater depth in 1886, and a greater mean slope, the velocity may have been little more than in 1882. The additional 0.9 foot, then, of gauge-height would not give a proportionate increase of discharge, and perhaps 1 600 000 would cover it.

The flood-line of 1883, from Memphis down, was almost parallel to that of 1882, and a trifle lower. The situation at Helena was very similar in every respect, and the discharge of the two years must have been nearly the same, 1883 being a little less.

There is a considerable resemblance between 1883 and 1886, as far down as Austin, the high-water marks of the two, where they can be compared, being usually very close together—the greater volume of the former being offset by the escape into the Yazoo Bottom, which from Memphis to Austin was, in 1883, estimated at 125 000. In 1886 it was perhaps 20 000—from a crevasse at Austin. There probably reached Austin, in 1883, about 1 675 000 feet of discharge—and not much less in 1886. This may serve for a rough check on the computations just made. From Austin down 1886 gained rapidly on 1883, owing to the closure of the numerous breaks in the Mississippi levees, whereby some 166 000 feet were added to the discharge.

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* High water observations of 1882, in Report of Mississippi River Commission for 1885.

† High water observations of 1886, in Report of Mississippi River Commission for 1887.

The reason that so much importance is attached to the discharge of 1886, is that it occurred substantially under the conditions that must prevail in the future. The White River Basin can be closed only for a limited distance, and whatever may be done there hereafter cannot greatly affect the result. If it could be known with exactitude how much water passed Helena at the height of the flood of that year, we could reason with considerable accuracy as to results to be reached in the river below. It is thought it may be assumed, keeping within the figures, at 1 600 000. Very possibly it was 1 650 000 or more.

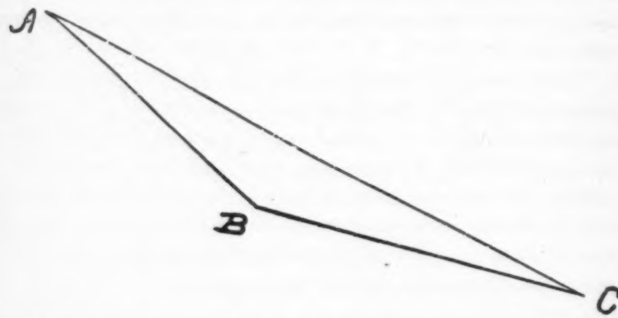
What may now be expected to happen when 200 000 feet are added to this? In 1882 such an increment raised the gauge only one foot, under the steep and constantly increasing slope just mentioned. Is this phenomenon likely to be repeated in the future?

In the first place, what was the effect of the crevasses above and below Helena, in 1882, on the slope, velocity and gauge-height? There were a series of crevasses in the neighborhood of Trotter's Landing, 3 to 10 miles above Helena, discharging about 150 000 feet, and three or four nearly opposite, discharging 21 080. There was a break just below Helena, on the White River Front, with a discharge of 63 000, and one a mile and a half above Delta, or 6.5 below Helena, with a discharge of 40 650, besides numerous smaller gaps, the most notable of which was six miles below Friar's Point, with a discharge of 28 000. Total from Helena to nineteen miles below, 181 700.*

Observation shows that a crevasse depresses the flood-line in its immediate vicinity, and to some extent both above and below—the principal part of the effect being local and at the crevasse itself; that is, there is a hollow in the high-water profile at that point, the slope being steepened above and flattened below. A crevasse above a given point diminishes the discharge at that point by the amount withdrawn, diminishes the velocity, and for that reason does not proportionally lessen the flood height. A crevasse below a given point increases the velocity and diminishes the flood height at that point. The diminution of flood height can never be equal to that which takes place at the crevasse itself. Let *A C* be the slope of a confined stream. Let a breach be made in the levee at *B*, depressing the flood-line at that point by one foot. This steepens the slope, increases the velocity and lowers the flood-line at *A*.

* Crevasse Observations of 1882, in Report of the Mississippi River Commission for 1884.

It cannot, however, lower it by so much as one foot. If it did, it would restore the slope to what it was, and the reduced gauge-height would not




be sufficient to pass the discharge. Moreover, in that case, the flatter slope from *B* to *C* would cause a "backing up" of the water at *B* and from there to *A*.

Now, in 1882, had there been no breaks, the slope Helena-Friar's Point could not have been less than in 1886, namely, 0.48.* The difference between this and the actual slopes (0.60 to Delta, 0.53 to Friar's Point) shows the maximum possible depression caused by the breaks of 1882, *i. e.*, 0.96 at Delta and 0.65 at Friar's Point. Therefore, had there even been no compensating influence in the shape of the breaks above, the water-line at Helena could not have been lowered by so much as one foot by the breaks below, and consequently a fraction of a foot more at Helena, had the levees been intact, would have carried all the discharge that passed there in the channel.

The great increase of velocity in 1882 which occurred at the height of the flood, and upon which so much stress is laid, could not have been materially assisted by the breaks at Helena and Delta. Those breaks had been discharging a long time when the great increase of slope occurred. Now the rise at Helena could not possibly have increased the discharge through the breaks by more than 20 000 feet—whereas, the increase of the discharge at Helena was 300 000. The steepening of

*If it be objected that 1886 had a greater discharge than 1882, and that the slope assumed is too steep, it is answered that in 1887, with a discharge confessedly less (by 170 000 or more) and a gauge-height 0.9' less than in 1882, and without a crevasse anywhere, the slope Helena-Friar's Point was 0.44.

the slope was therefore not due to the crevasses below, and would not have been, had there been none above to compensate them.

As things actually were, the great breaks above and below produced opposite effects and offset one another, so that the slope was not essentially altered.

There is no reason, therefore, why the experience of 1882 should not be repeated. The very nature of an engorgement arising from the cause supposed—that is, from a sudden influx of dead water—necessarily implies a steepening greater than the ordinary, followed by a "flattening out." Had the flood gone still higher, there is no reason to doubt that the slope and the velocity would have gone on increasing. The same reasons which availed to increase the slope to 0.51 would have brought it to 0.60 or so, which is about what would be required to pass 1 800 000 feet at an additional elevation of one foot. The velocity required would be 7.55.

In the meantime the regimen of the river has undergone a change. The channel from Trotter's to Friar's Point has suffered the natural consequence of the immense losses of water which it experienced, and a manifest deterioration has taken place.* This process has already been alluded to. Many years ago, it was explained with great force and clearness by Major Barnard,† who remarked that a very short time was required for its operation to become manifest. "One season of high water," says he, "is sufficient to complete the change; the succeeding rise in the river being governed by the new order of things." By so much the more should a marked silting up of the channel follow three such extraordinary floods as those of 1882, 1883 and 1884.

Accordingly, in 1886, with a discharge perhaps not much more than in 1882, the river was 1.47 higher at Trotter's, 0.9 higher at Helena and 1.38 higher at Friar's Point. Therefore the flood-line has probably been raised materially. Were the discharge of that year known with precision, we should have an accurate measure of this rise.

The violent change brought about by the sudden rebuilding of the Mississippi levees has now done its worst. The new regimen of the river has been established. Should another 1882 come, it will find the situation the same as before, except for the elevation of the flood-line perhaps

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*This is the opinion of Major Dabney, Chief Engineer of the Yazoo-Mississippi Levee District. See his Report of August 21st, 1888.

†In his well known letter to Mr. G. W. R. Bayley, printed at Baton Rouge in 1860.

the greater part of a foot.* The recurrence of the same conditions will bring about substantially the same results. The conclusion I draw is that the experience of 1882 is a safe precedent for the future; and that one foot above 1886, or a gauge-height of 49.1, is likely to be sufficient to carry off a discharge of 1 800 000 feet. It must not be forgotten, however, that at the turning point of a flood, the velocity is sometimes slackened a little,† and a margin of safety of a foot might be required, so far as Helena itself is concerned.

In considering the reach from Helena to Arkansas City, the experience of 1886 will not be a safe guide. It is true that the two or three breaks in the upper Levee District of Mississippi were insignificant—but there were considerable gaps in the levee at the foot of the White River Basin, which divides that area from the Tensas Basin. In 1887, however, this line was held, as well as all the Mississippi levees. Moreover, the high water discharge was measured at Arkansas City. Therefore, we shall have to rely mainly upon what we can learn from this flood and that of 1888.

The flood of 1887 did not reach so great a height as 1886 at Cairo, New Madrid, Helena or Arkansas City, but it was in total volume greater than 1886, and accordingly produced a more considerable effect in the lower part of the Mississippi Valley. It is too often forgotten that an extreme gauge-height at the head of an alluvial valley is not at all an exact criterion of the magnitude of a flood lower down. A high and short wave, when "flattened out," may be of less significance than a long one of less height. Duration of a flood, therefore, is of fully as great consequence, as regards gauge-heights below, as elevation—and the maximum discharge at Cairo or Columbus does not afford any certain indication of the height to be reached at Vicksburg or Red River.

The discharge of 1887 at Arkansas City, as measured, varied from 1 417 408 to 1 491 735, with a probable value of about 1 440 000 and a probable velocity of 6.15.‡ With the White and Arkansas Rivers at low stages, this should indicate a discharge at Helena of about 1 390 000 and a velocity of about 6.00. The same conclusion is reached from the

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* Of course on the supposition that the assumed discharge of 1 600 000 is correct. It may have been more. It can hardly have been less. In either case, the reasoning is not affected, except quantitatively.

† See Humphreys and Abbot, page 345, the Helena observations of 1882, and the Columbus observations of the same year, in Report of the Mississippi River Commission for 1883.

‡ Report of the Chief of Engineers for 1887, page 2888.

gauge-heights and slopes at Columbus and Helena. The stage at the latter point was 46.3.

The high water of 1888 hardly deserved the name of a flood at Helena. It was measured at Wilson's Point, with a discharge of about 1 200 000.* White River and the Arkansas were at a medium stage, and contributed probably about 80 000 feet, so that it is probable that not more than 1 120 000 passed Helena, at a stage of 42.8. The stage at Arkansas City was 45.2.

Captain Rossell † has made a careful tabulation of the movements of the Cairo, Helena and Arkansas City gauges for the different wave crests from 1880 to 1886 inclusive. From these tables it appears that the Arkansas City gauge is almost uniformly the higher. For gauge-heights from 30 to 40 feet the mean superiority is 0.82 feet. For heights over 40 it is about 1.2. From this estimate are excluded such observations as were taken when the levees were broken and the river out of its banks during the great flood-years. Such data are evidently of little value. They would reduce the above average to about 0.10. The only high-water observation that is available is that of 1887. In this year the Helena gauge stood at 46.3, the Arkansas City gauge at 46.85.‡ Fortunately, too, the Arkansas and White Rivers were both low. Probably their joint discharge did not exceed 50 000 feet.

Generally the difference between the two gauges is fairly attributable to the discharge of the tributaries; or rather this over-compensates the difference; that is, an equal stage at the lower station is sufficient to carry off not only the discharge at Helena, but also a portion of the increment received. According to the observations of 1884–85, the difference in discharge in favor of Arkansas City varies from 25 000 to 100 000 feet. We may therefore adopt the least favorable assumption that the reading of 46.3 on the Helena gauge represented an equal discharge at the same stage at Arkansas City.

If no tributaries intervened, and the river were confined between levees all the way from Helena to Arkansas City, then the high-water gauge-height at the latter place could never equal that at the former.

* MS. communication of Captain W. T. Rossell, Corps of Engineers, U. S. A., and Arthur Hider, Esq., M. Am. Soc. C. E., United States Assistant Engineer.

† In an unprinted paper laid before the members of the Mississippi River Commission in 1888.

‡ There is a little discrepancy here. This is the official record; but the reading reported by Mr. Childs, who took the discharge measurements, was 46.63. See report of Chief of Engineers for 1887, page 2888.

After the mean high-water slope has been attained, at which the velocity is constant at all stations, then any addition from above must result in an acceleration of that velocity; therefore the cross-section below will not increase in proportion to that above, and the greater the flood, the more striking will be the disproportion. How great this may be we have no means of knowing. We must content ourselves with the conviction above expressed. If, therefore, the flood-plane be assumed as equal in elevation to the mean (it is really above it), then an addition to that elevation of, say, 2.7 feet at Helena could never result in as great an elevation at Arkansas City, under the circumstances supposed; and the gauge-height at the latter place could never equal the assumed maximum of 49 feet. If the velocity of 7.55 at Helena be maintained at Arkansas City, it will pass the discharge of 1 800 000 at a height of 48.16. It is not asserted that the velocity will never be diminished. It will be subject to local variations, from difference in conformation and dimensions of cross-section, from the effect of bends, shoals, islands, etc. It is probable also that the descent down a very steep slope, as below Helena, where there are no bends to check the acceleration, will result in an impingement against the bottom, a scour and a flattened slope beyond. All these variations, however, will be self-compensating—will be merely oscillations, in fact—and as a whole the velocity should increase, when above mean flood-line, until a change of slope occurs from a fall above.

This reasoning cannot be verified, at this time, by testimony derived from facts, because the distance from Helena to Arkansas City is so great (132 miles) and the relations between them so changed by the interposition of the tributaries that a comparison between their daily gauge records is fruitless.

What will be now the disturbance produced by the White River Basin and the tributaries? As to the former, it is thought, as already intimated, that its effect cannot be very great; and in assuming the flood-line of 1887 as the standard, we have included the modifying effect of the reservoir, whatever it may be. The maximum discharge of the tributaries I suppose to be about 300 000 feet.* We have a rough way of getting at the effect of this discharge on the flood-line at Arkansas City from the records of 1885. There were great freshets in the White and

* See Plate III of Colonel Suter's paper on the Investigation of Discharge Measurements; Mississippi River Commission print, 1888.

Arkansas Rivers in both January and April-May of that year. The latter fortunately coincided almost precisely with the culmination of the rise in the Mississippi, so that by comparing the height of the wave-crests at Helena and Arkansas City (knowing approximately the ordinary relation which subsists between those gauges, supposed to be that of equality), it is easy to see what was the effect of the increment from the tributaries. The gauge-reading at Helena on May 4th was 38.75. At Arkansas City on May 8th it was 42.60. Therefore the rise due to the discharge of the tributaries, which were nearly at their maximum flood height, was 3.85 feet. The discharge at Helena I suppose to have been about 920 000 feet, and the velocity about 4.7. At Arkansas City, after the increment, it was probably about 5.4.* Now the effect of a given increment upon the height of a flood should be inversely as its velocity. If the velocity before the increment be 7.55, the increase of height at Arkansas City will be 2.33, and the gauge-reading 50.49. The velocity at Arkansas City will be 8.52.

These velocities seem very great, yet they are not entirely beyond example. At Columbus, in 1882, the velocity is thought to have reached 8.3, and in 1858, if the reductions of Humphreys and Abbot may be depended upon, a velocity of 8.47 was attained. We must remember that we are treating of unexampled matters. Man has never seen such a discharge as 2 100 000 feet in one channel, and when he does see it, it will be accompanied by equally extraordinary attributes.

We cannot receive the evidence of the high-water discharges at Arkansas City, especially that of 1887, in support of any estimate to be made for the future, for the reason that we cannot expect the circumstances under which it was made to be repeated. The slope Helena-Arkansas City of that year will indeed occur again, and probably even a steeper—but the slope Arkansas City-Greenville in 1887 was 0.35, and it is not likely that this will be paralleled, still less exceeded. It is not necessary that it should be—for Arkansas City is only to a limited extent an origin of velocities; on the contrary, it is believed that the river will reach there with a velocity already sufficient for its purpose. We may rely upon the long fall, at extreme flood height, with a steep slope, from Helena, and upon the volume, already beyond any previous

* Unfortunately the discharge measurements at Helena and Arkansas City in 1884-85 were discontinued just before this time. I can only infer from parity of stage in the January rise.

example at Helena, and now further augmented, it may be, at the mouth of White River. If a discharge of perhaps 1 150 000 in 1885 increased its velocity from 4.7 to 5.4, it will not be more difficult for a discharge of 2 100 000 to increase from 7.55 to 8.5.

In considering the reach from Arkansas City to Vicksburg, it will be possible to bring the reasoning hitherto employed to the test of fact —there being two important circumstances to guide us. First we have had the invaluable experience of a perfectly confined river, up to extreme high-water mark throughout a great part of the reach; and secondly, we have stations so near together that their slope may be compared day by day, and where daily records have been kept for several years.

The year alluded to was 1888. As has been already remarked, above this reach the river was only moderately high. At Arkansas City the gauge stood at 45.2—being 1.8 below high-water mark ; at Greenville it was 1.2 below, at Longwood up to high-water mark—which elevation was maintained about to Mayersville. At Lake Providence the gauge was 0.22 below high-water mark, the disparity increasing thence to Vicksburg, where it stood at 44.2 on the gauge—4.6 below 1882, or 4.8 below 1884.

There is no difficulty in understanding this condition. For the last twenty-five years the water has had free escape over the right bank (the front of the Tensas Basin), and had accommodated itself to this order of things. Consequently the bottom of the bed has been actually raised, and the slope above flattened accordingly.

The low water slope between Arkansas City and Vicksburg* conveys to the eye a pretty correct idea of the condition of a deteriorated reach—and the high-water slope of 1882 carries with it the explanation of that deterioration. Most of the great depressions in that line (as near Point Comfort, above Sunnyside, from Grand Lake to Ashton, and in the neighborhood of Edgewood)† coincide precisely with great crevasses, sometimes apparently assisted by escape over "points." In the low-water line, these depressions are represented by elevations and the general shape of that line is convex from Arkansas City to Vicksburg.

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* See Plate XLIV.

† There is reason to believe that the reported high-water mark of 1882 at this point is altogether too low. It does not correspond with the high-water elevations reported in that vicinity on the Mississippi side.

It was remarked at the beginning of this paper, in speaking of the high-water slope Arkansas City-Greenville, that there was a progressive steepening of slope, in that instance, in harmony with the increase of gauge-height. The same observation may be made of the slope Greenville-Lake Providence. But below this the remark ceases to hold good. If we take the slope Lake Providence-Vicksburg (Plate XLIV), we shall find precisely the opposite condition to prevail. The slope is steeper at low water than at high, becoming flatter and flatter as the gauge rises ; and the progression is steady and tolerably uniform. It is plain from all that has been said, and indeed from the appearance of the high-water profile of 1882, that the slope of that year was entirely abnormal. Let the year 1885 be taken, when the river was almost within its banks—and again, 1888. They exhibit a progressive departure from the low-water type. But this departure must have an end. The slope Arkansas City-Lake Providence cannot go on increasing and the slope Lake Providence-Vicksburg go on diminishing. There must be a limit to which they are continually approximating, and which once reached will be maintained, except for the steepening beyond mean flood-line ; and irregularities will disappear as far as may be consistent with the constraint imposed by the deteriorated bed ; and in due time the deterioration will be rectified, and the slope assume its normal shape.

The causes of these antagonistic movements are already known to us, and are implicitly included in the statement that the oscillation at intermediate stations is less than at the mouths of tributaries or the outfalls of basin-drainage.

By inspection it will be perceived that the direct relation of gauge and slope terminates and the inverse relation begins at about Ashton. The year 1888 is an excellent one for the comparison, as the river also attained an extremely low stage. The records are scanty, but sufficient for our purpose.* The slopes are as follows:

| | Low Water. | High Water. |
|---|---|---|
| Arkansas City-Greenville, | .169 | .323 |
| Greenville-Lake Providence | .293 | .327 |
| Lake Providence-Vicksburg | .509 | .307 |
| Arkansas City-Vicksburg | .339 | .319 |

The limit toward which these relations tend is very obvious. In fact, it has already been attained or passed, and may be fixed at a mean

*High and low water observations of 1888, in the Report of the Mississippi River Commission for that year.

slope of 0.32 foot to the mile, or somewhat less, between Arkansas City and Vicksburg—probably a little more in the upper part of the reach, and a little less in the lower. This slope is evidently modified, by the deterioration of the bed or other local peculiarities, to a certain extent, as is shown by the high-water profile. Thus, the slope Greenville-Longwood is only 0.25; the slope Longwood-Mayersville, 0.36; Mayersville-Lake Providence, 0.40.

These irregularities produce only local effects. They have no agency in modifying the mean high-water slope Arkansas City-Vicksburg. What is lost in velocity in passing from a steep to a flat slope is regained in the transition from that flat slope to the next steeper; and the general result on the oscillation at Vicksburg is about the same as if the slope had been uniform. Also, the local differences of elevation corresponding to an increased height at Arkansas City will be governed by the same law. The effect of scour is, of course, for the present excluded.

What the "flattening out" may be between Arkansas City and Vicksburg it is not easy to say. It depends, in fact, on the height, duration and nature of the wave. The first wave of 1885, in which the flood (a very great one) from the White and Arkansas Rivers did not coincide with the rise in the Mississippi, was at Arkansas City 3.5 below the high water of 1888, which will henceforth, for this reach, be assumed and denominated as the standard. At Vicksburg the difference was only 1.8, indicating a slope of 0.308. For the second wave, wherein the coincidence of the two floods was almost perfect, the differences were respectively 2.6 and 3.3, and the slope 0.323. It must be remembered that the Yazoo itself is a considerable river, and its modifying influence is sometimes strongly felt, as in the first wave of 1885, just mentioned, when it was at its height when the Mississippi flood reached Vicksburg.

We cannot pretend to minute accuracy in estimating all these disturbing causes. We have a right to expect that there should be a gradual increase of slope as the gauge rises above mean flood height, but in the absence of any precise information we will take the safest plan, and assume that slopes above mean high water will be parallel to that slope, and that consequently a rise above that plane of, say, 5 feet at Arkansas City will be attended with a like rise at Vicksburg, and also at all intermediate points in the reach. In taking 1888 as the standard we have also kept on the safe side, as it was a flood above the mean. This additional height of 5 feet cannot be exceeded, except to a

limited extent, in the case of a flood beyond the ordinary in the Yazoo, and may be diminished to an unknown extent, depending on the nature of the flood above.

How does this accord with observed facts? In the first place, the reasoning itself, in this instance, is founded on facts. It is true that the same conclusion was reached before on theoretical grounds; but here it is independent of theory. If it be said that the capacity of the stream in the confined reach is not sufficient to carry the discharge which will thus pass Arkansas City, the answer is that that capacity has already been tested in 1888. Take a stream of nearly constant cross-section, flowing in a bed of its own formation, which has carried 1 200 000 feet of discharge at a given height, and add to it 900 000 feet. If it carries it at its upper end, by so much the more will it carry it at its lower. If it be said that by the reduced dimensions of the channel below an engorgement will take place—the water being "backed up" at Arkansas City—it is answered that the engorgement has already taken place (in 1888), and the regimen adjusted to that condition. If it be claimed that the cross-sections below are unfavorable to the passage of the discharge, and that the resistance will be proportionally increased, it is answered that this reasoning is diametrically wrong, if by an unfavorable cross-section be meant a shallow one. An increase of depth in a shallow cross-section is proportionally more favorable to an increase of velocity than in a deep one. An increase of depth of 5 feet in a cross-section 10 feet deep means an increase of velocity of 22 per cent. The same addition to a cross-section 50 feet deep will cause a velocity-increment of only 5 per cent. The danger rather lies in the very deep and narrow places, and they are mostly in bends, and the escape of the water is facilitated over the "points." If the number of narrow places be limited, the efforts of the stream at a high velocity will easily suffice to enlarge them to the requisite extent in a single season. If it be said that as a matter of measurement the cross-sections below are so small that they cannot pass the increased discharge without an excessive elevation of the flood-line or an excessive augmentation of velocity, the fact is denied. If it be thought that the measurements at Hays' Landing in 1882 * support this assertion, such an idea is easily exploded by an examination of the circumstances of that case. The observation station was at Bass's Land-

* Report of Mississippi River Commission for 1883.

ing, on Point Lookout, at a distance of 2 miles or so outside the levee, and with an abundance of low ground for the escape of water across the point. This is a very considerable feature of the flow of the river, and too little importance has been attached to it. So far as I know, the only measurements of these great movements that have ever been made are given in the crevasse discharges of the St. Francis Front in 1882 and 1883. They sometimes amount to 100 000 feet at a time.

It is not practicable to make an accurate estimate of the areas from the soundings plotted on the maps, and there are but few situations where the river is sufficiently confined to make such measurements useful, but here are a few approximations obtained in this way, from the maps to a scale of 1 to 20 000 recently issued. They are given without selection:

| Leota. | Homochitta. | Shipland. |
|---|---|---|
| 215 875 | 224 040 | 230 480 |
| 219 850 | 223 340 | |
| 217 020 | | |

There are few places indeed where the levees are less than 6 000 or 7 000 feet apart, and although the discharge outside the banks is frequently not great, in other cases it is considerable, and may give a welcome relief during the process of readjustment.

Of course it is not possible that so great a velocity as 8.5 or more can be maintained for any considerable time without causing serious disturbances of the regimen. The great flood of 1882 was above mean high-water stage about two or three months, and during half of that time it was within 3 or 4 feet of its maximum. Such tremendous forces, operating for even a brief period, must act powerfully against both banks and bed, all equilibrium being utterly destroyed. Part of this action will be beneficial, and will aid in the reclamation of the channel and the lowering of the flood-line in the deteriorated places. Part will be destructive, in the effort of the stream to gain the length demanded by the new and increased velocity. It is to be hoped that a series of moderate floods may aid in effecting a gradual transformation before the advent of another 1882.

To sum up the above reasoning, it is evident that the foundation of it is the high-water stage to be attained at Helena; and it is thought to have been shown that the condition of 1882 will be in all essential respects repeated, and that the gauge height there will not exceed 49 or at most 50 feet, and the velocity 7.55.

This velocity, not being imposed by extraneous circumstances, but being acquired by fall in a bed of nearly constant cross-section prepared by the stream itself for a lower stage, will not be lost, but, on the contrary, will be accelerated as it progresses. Therefore, the current will reach White River with at least that velocity, and if there be no considerable accession from the tributaries, will pass Arkansas City at a stage of about 48.2.*

If at White River there be a large accession, then the river, by its increased volume, will acquire velocity enough to pass Arkansas City at an extreme height not more than 2.3 feet above the stage just mentioned, or at 50.5.

Taking below Arkansas City as a standard the high-water slope of 1888, then the height attained above that surface at Arkansas City will not be exceeded throughout the reach from Arkansas City to Vicksburg—and if at Arkansas City the height above that surface be 5.3 (equal to 50.5 on the gauge), then at Vicksburg the gauge will not exceed 49.5, and will probably not be as much as that.

Conclusion: From Helena to White River, the flood-height may progress from 2.8 to 3.6 feet above the high water of 1887, equal to — 0.4 to + 0.4 above existing grades. From White River to Arkansas City, 3.6 above 1887, = 0.4 above existing grade. From Arkansas City to Vicksburg, 5.3 above the high water of 1888, = 0.3 above existing grade. For safety 1 foot should be added to the above heights for the reason formerly given at Helena—namely, that the river sometimes continues to rise a little after the height of the discharge has passed.

I would rather have given a few solid facts than mere deductions, be they never so plausible. The problem, however, presses for solution, and will not wait. The only facts that can be of material service to us will be the results of high-water experience; and it is that very experience that those interested must anticipate and be prepared against if they would avoid the risk of severe injury. If, then, we have no certain grounds to go on, we must make the best of such imperfect data as we have, and supplement them with such reasoning as may be thought conformable to science and consistent with experience.

It is not claimed that the above conclusions have been proved. It is thought, however, to have been shown that it is possible and easy

* The increase at the mouth of White River from the influx of the tributary waters will be offset by the reservoir effect at Arkansas City.

for the greatest discharge ever known to be passed between levees at a height that is not extravagant, and that there is good reason to believe that the estimates here made are sufficient, and indeed rather in excess of the truth.*

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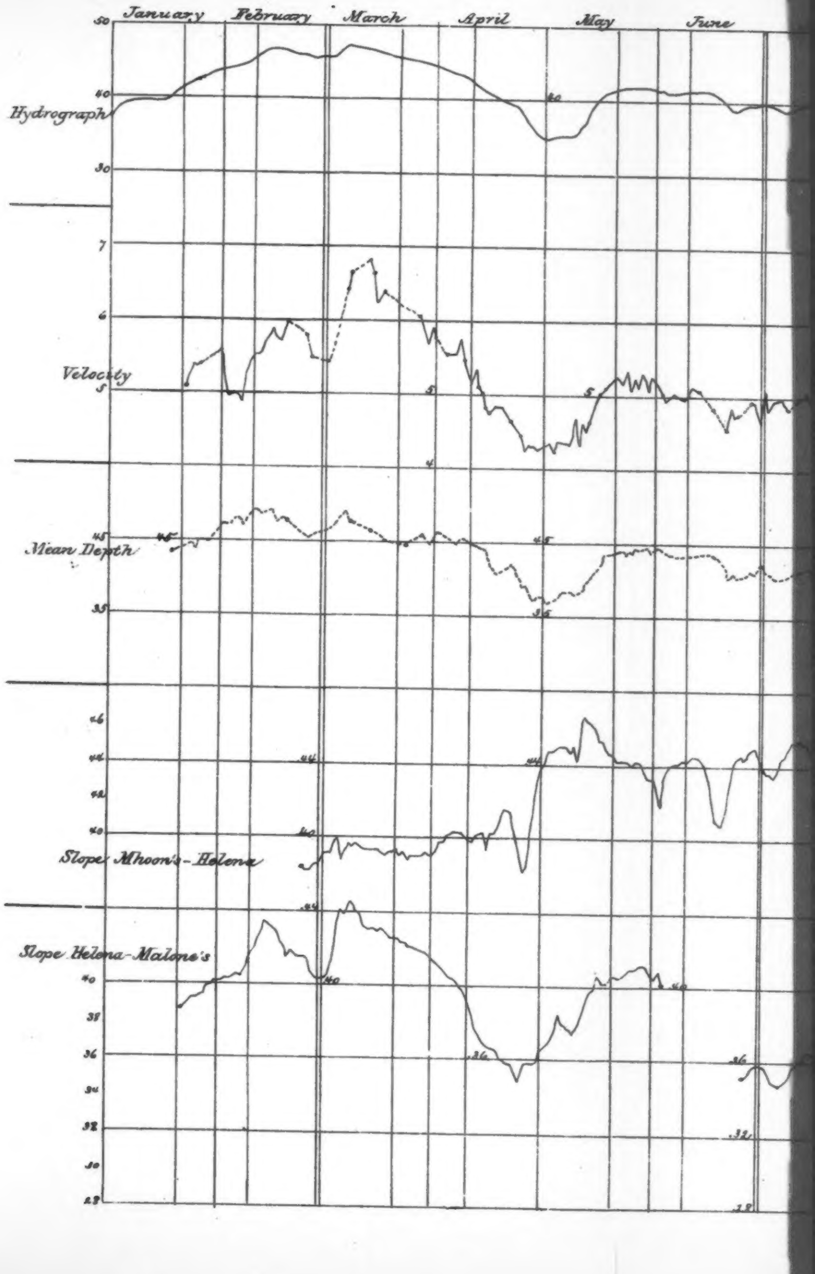
The illustrations accompanying this paper are:



* The writer must record his deep sense of indebtedness to the Mississippi River Commission, whose labors alone have rendered such an investigation as the above possible. He must also acknowledge his obligations to individual members of the Commission, and of the officers of the Corps of Engineers engaged in the work of river improvement, for unpublished data of essential value.


January
February
March
April
May
June
Hydrograph
Velocity
Mean Depth
Slope Mhoon's-Helena
Slope Helena-Malone's
50
40
30
7
6
5
4
45
35
46
44
42
40
38
36
34
32
30
28

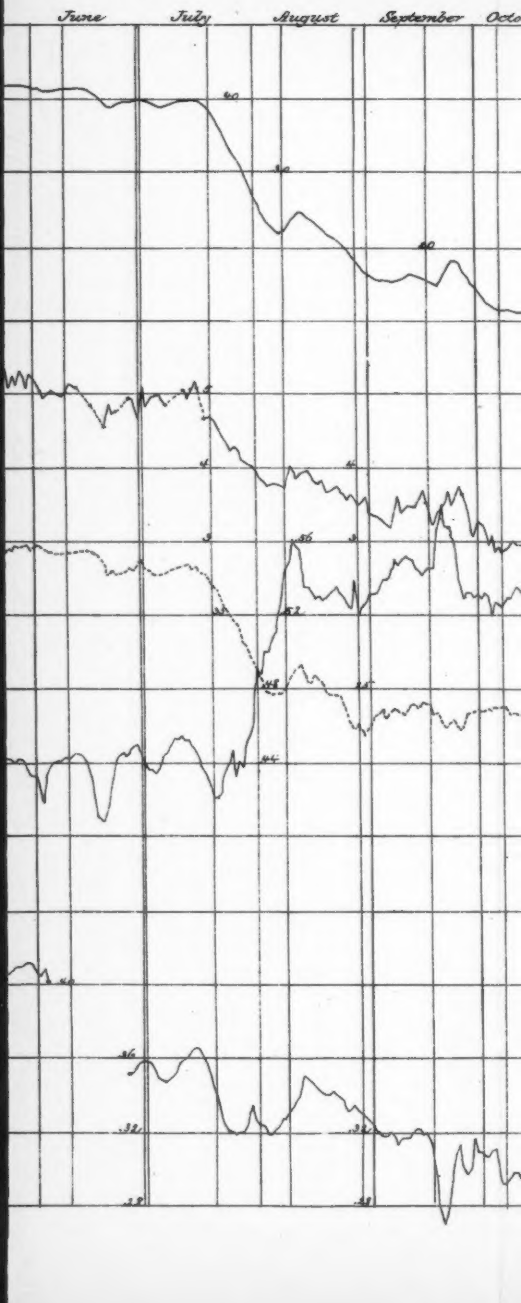
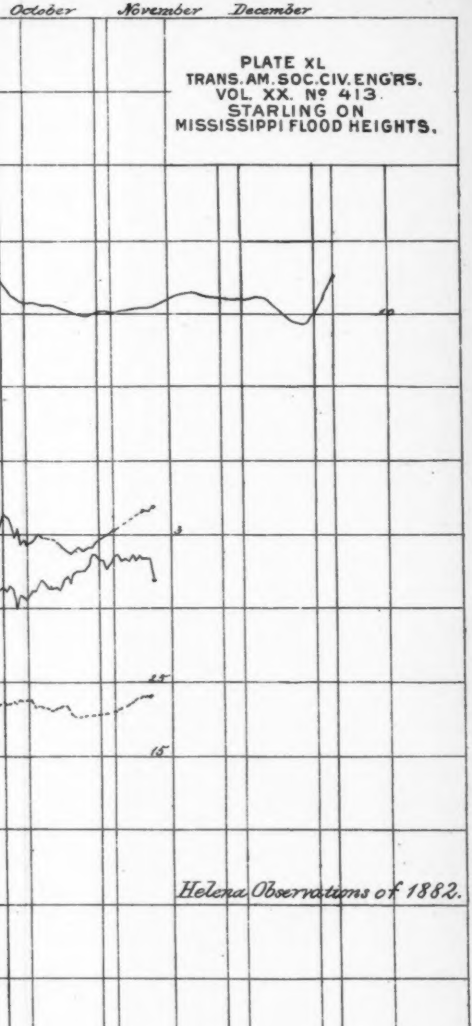
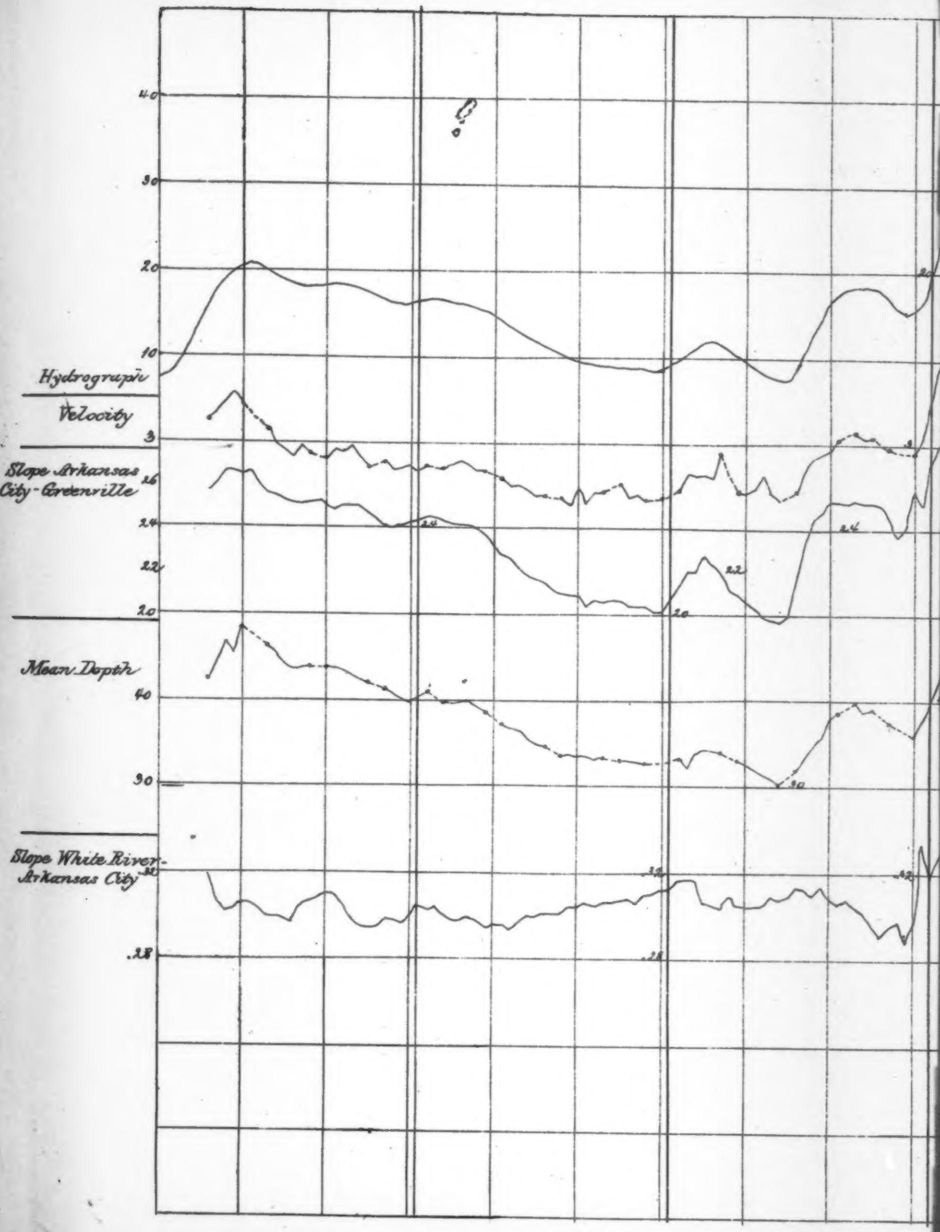

June
July
August
September
Octo
40
30
20
5
4
4
3
56
3
52
37
48
25
44
.40
.36
.32
.32
.28
.28

PLATE XL
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX. Nº 413.
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.





Hydrograph
Velocity
Slope Arkansas City-Greenville
Mean Depth
Slope White River-Arkansas City
40
30
20
10
3
2.6
2.4
2.2
2.0
40
30
.30
.28

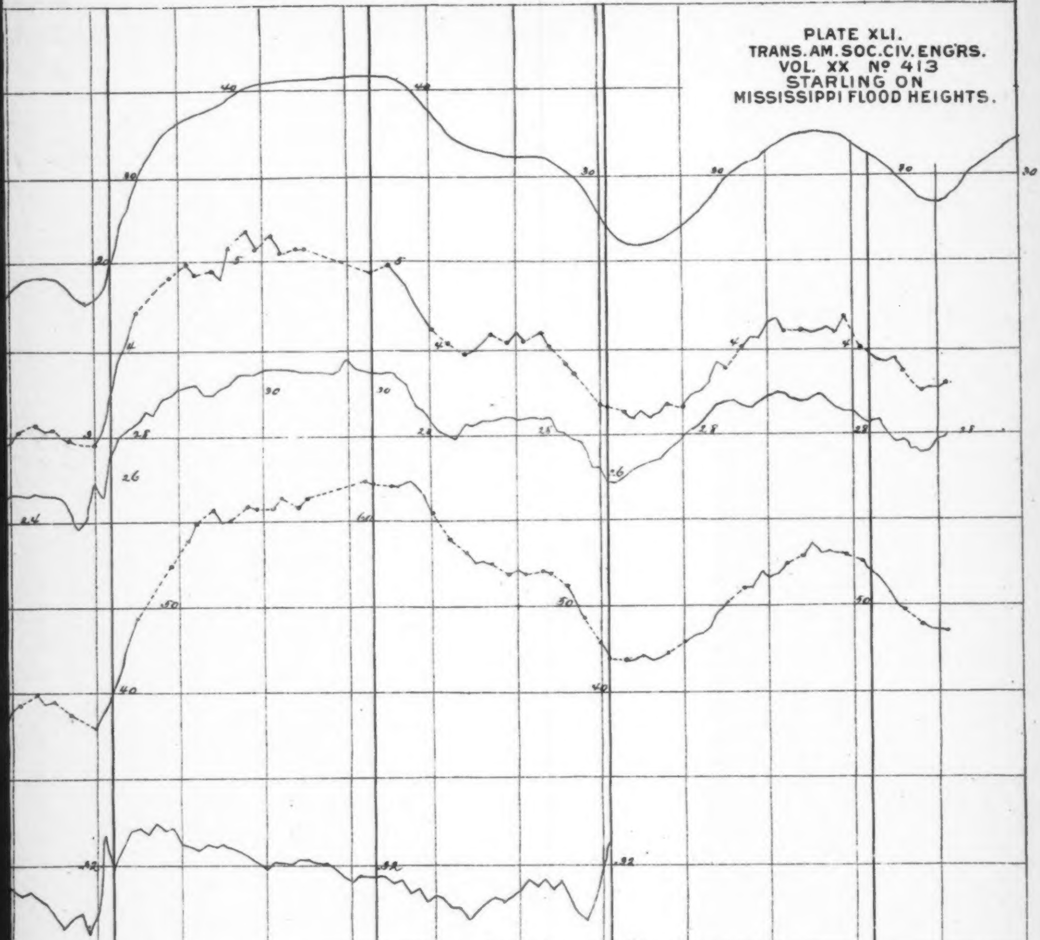
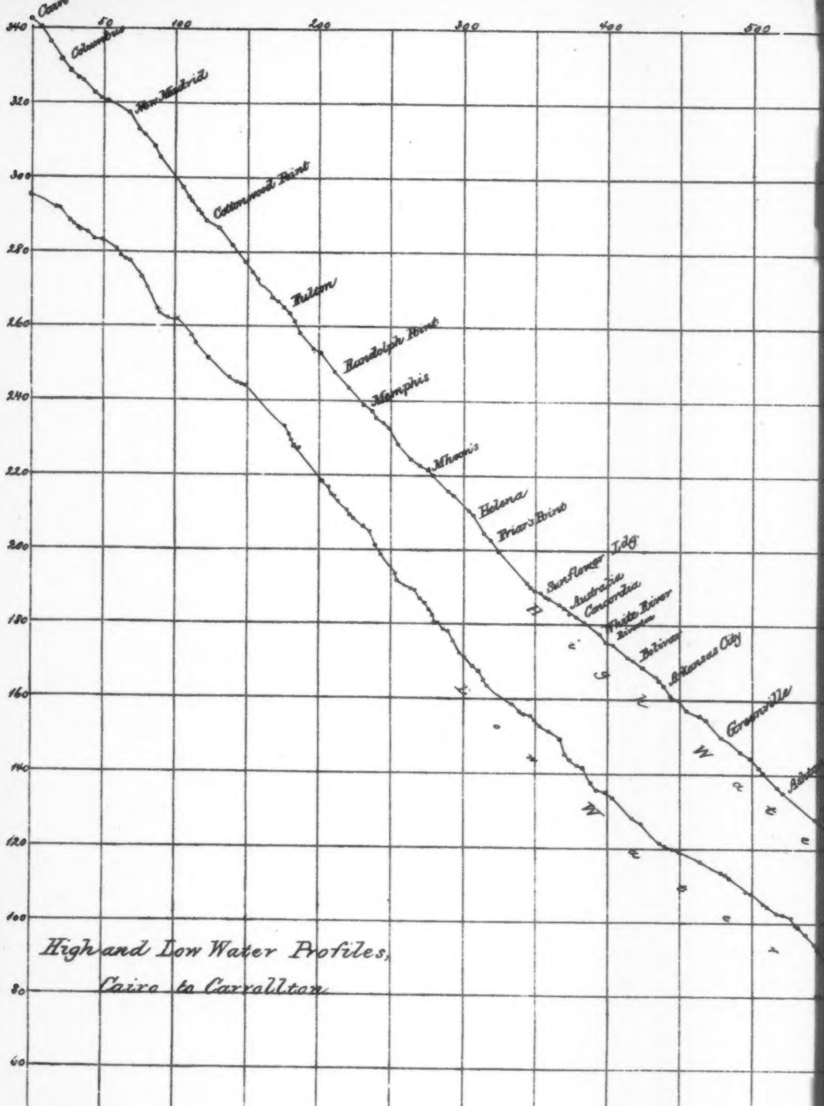
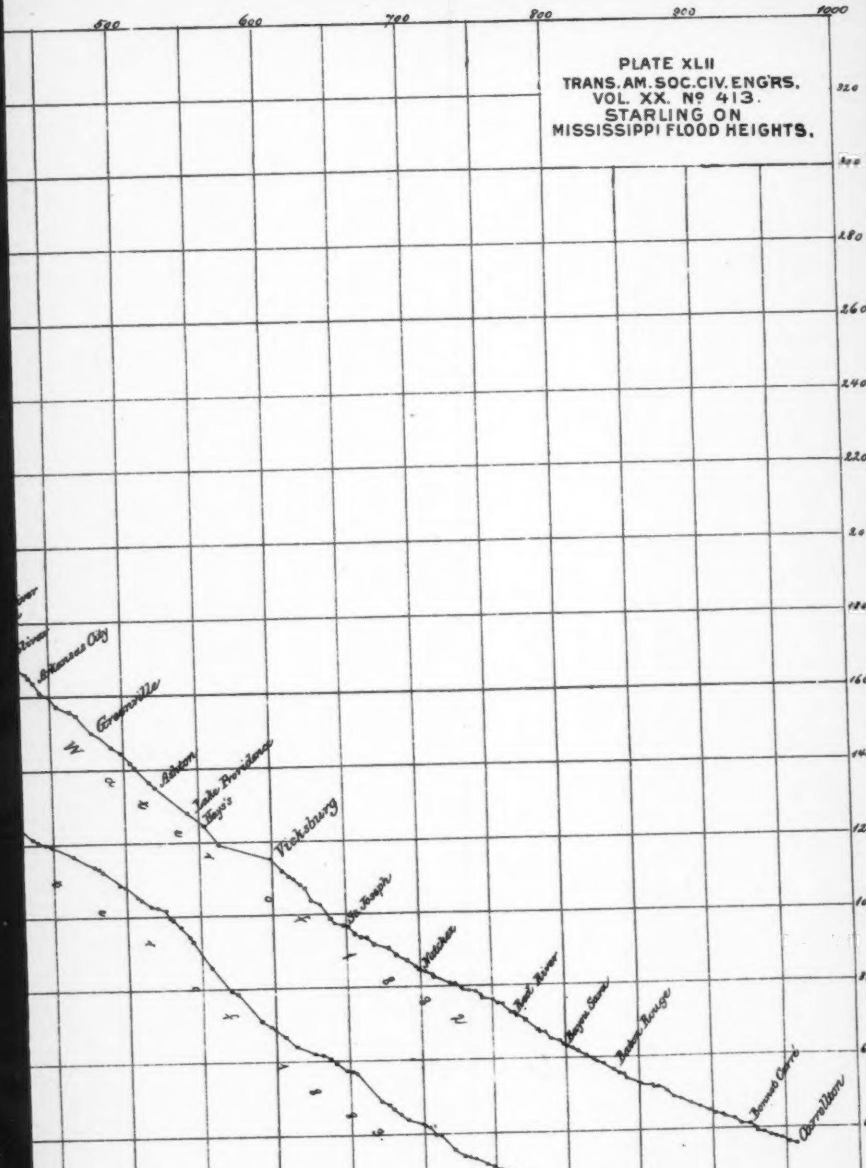


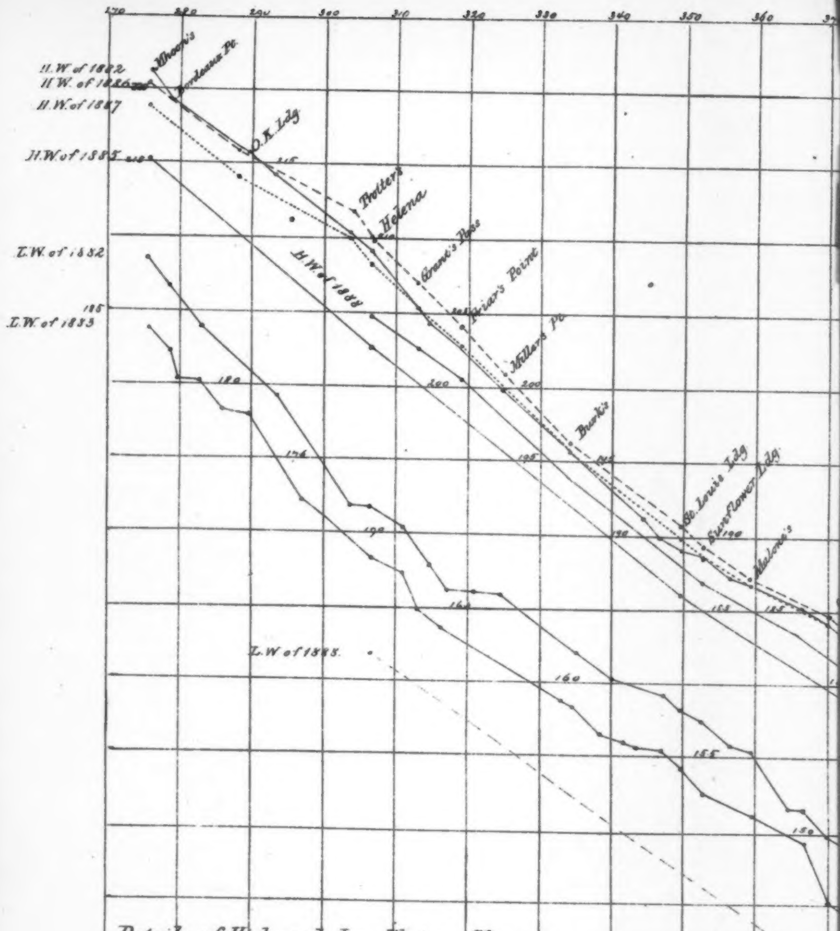
PLATE XLI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX Nº 413
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.
Arkansas City
Observations of 1884-5.




High and Low Water Profiles, Cairo to Carrollton.

PLATE XLII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX. Nº 413.
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.

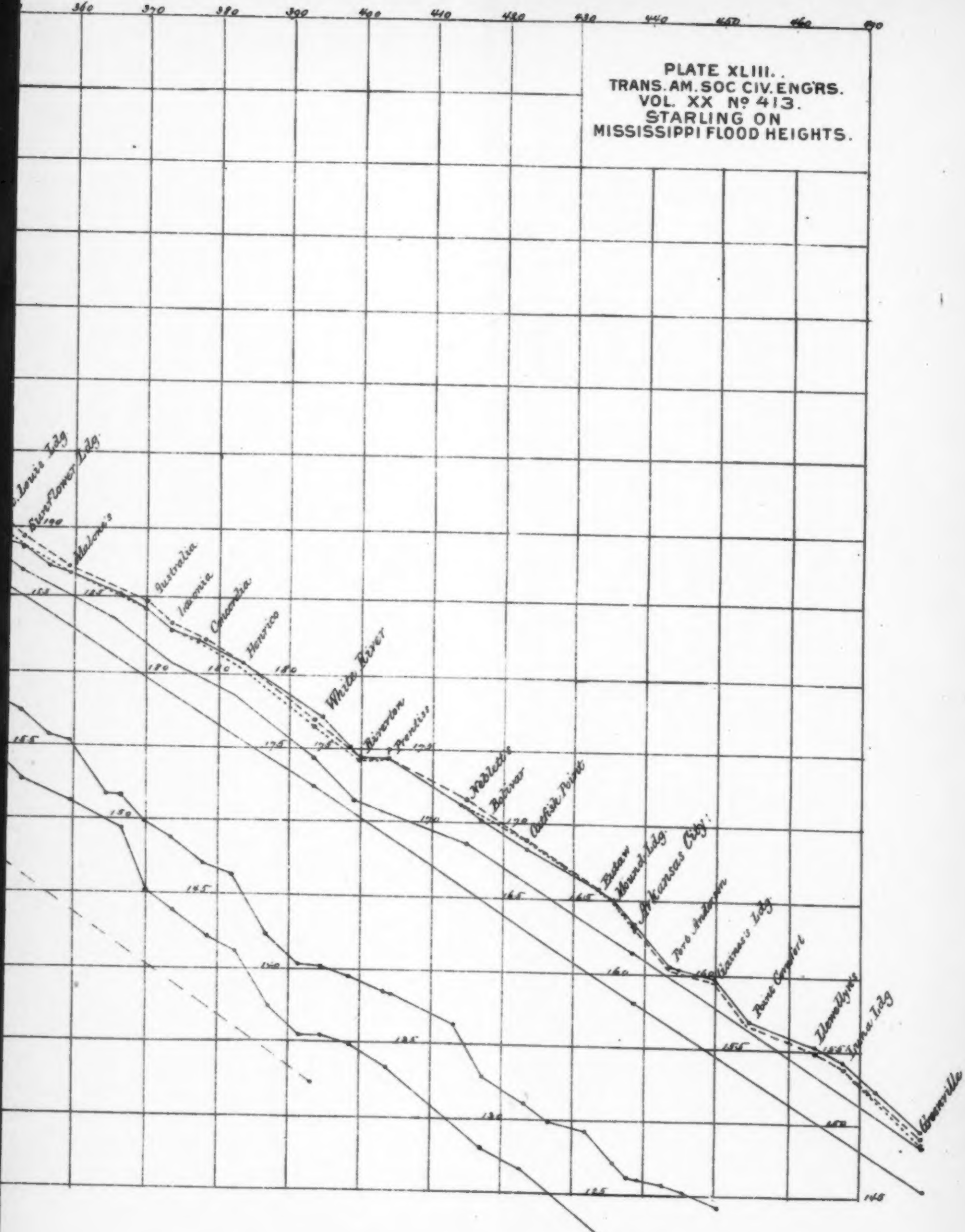


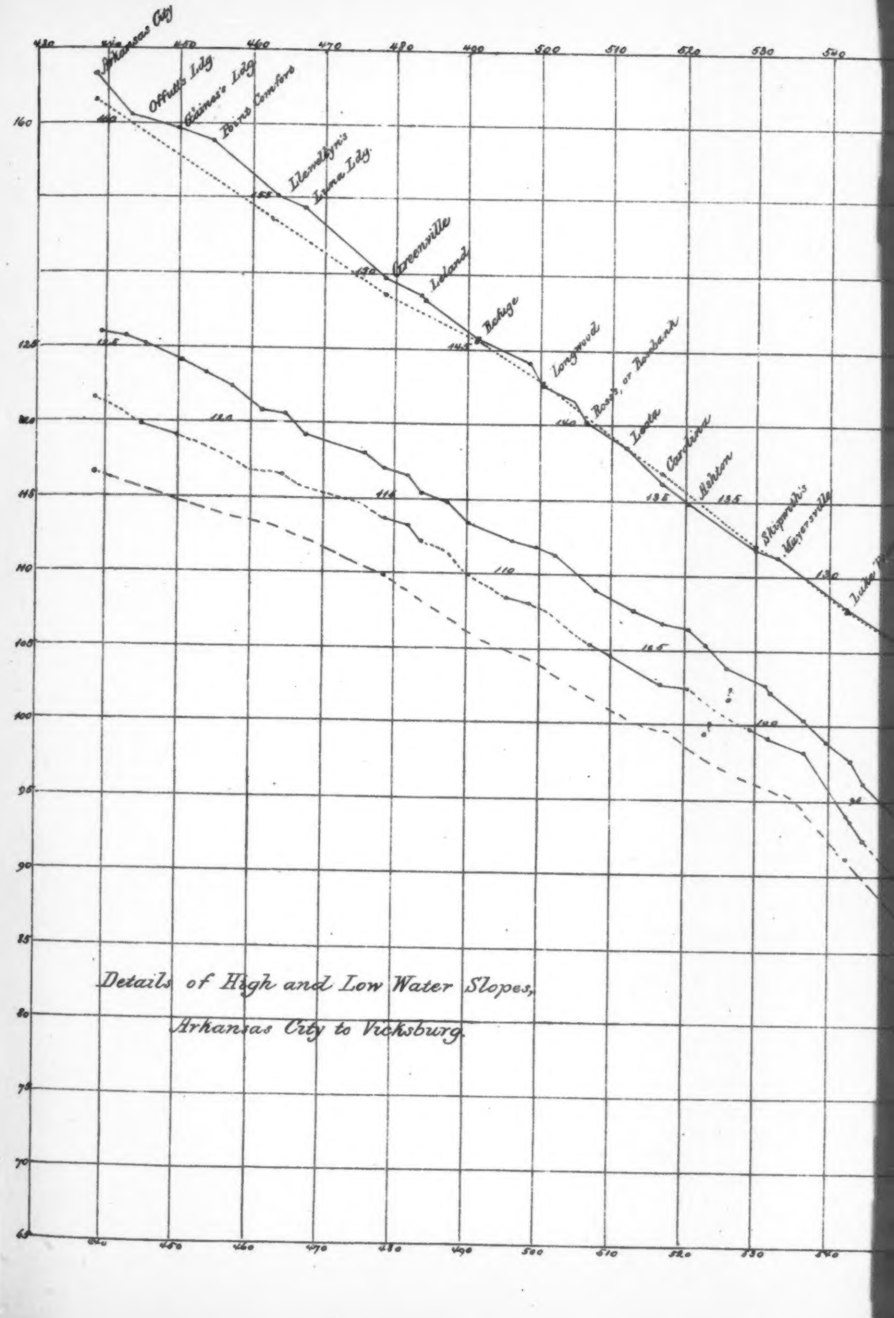



*Details of High and Low Water Slopes,*

*Mhoon's to Arkansas City.*

PLATE XLIII.
TRANS. AM. SOC CIV. ENG'RS.
VOL. XX Nº 413.
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.





Arkansas City
Offutt's Ldg
Gaines's Ldg
Point Comfort
Llewellyn's
Luna Ldg.
Greenville
Leland
Refuge
Longwood
Ross's, or Rosebank
Leota
Carolina
Belton
Skipwith's
Mayersville
Details of High and Low Water Slopes,
Arkansas City to Vicksburg.

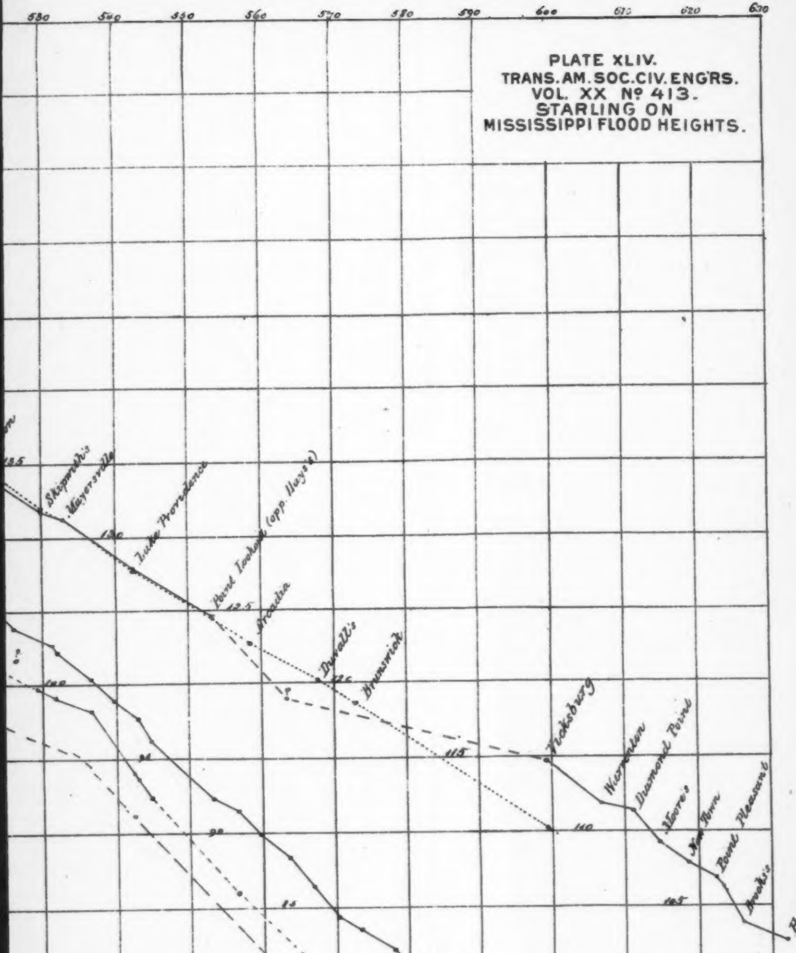
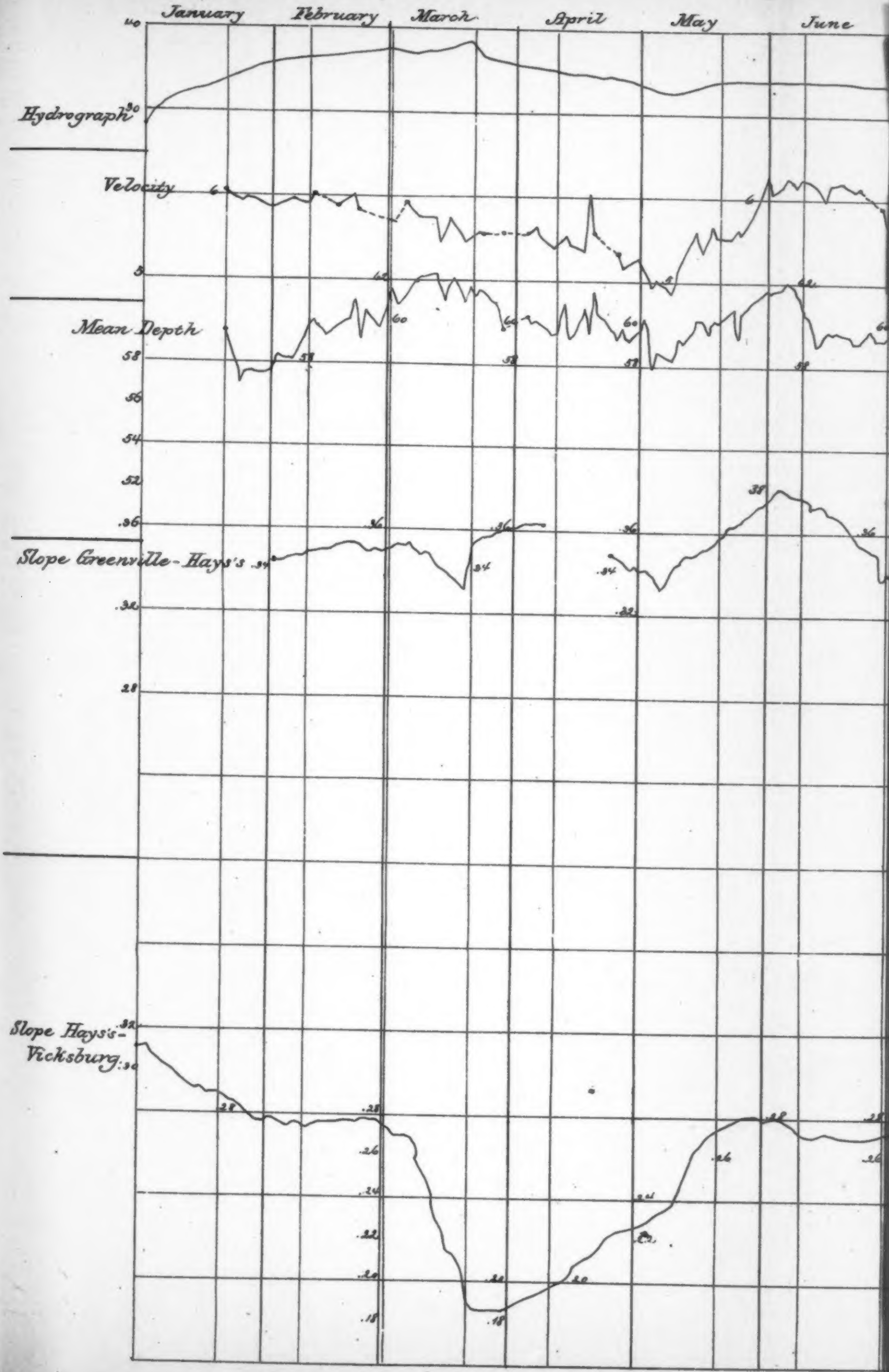
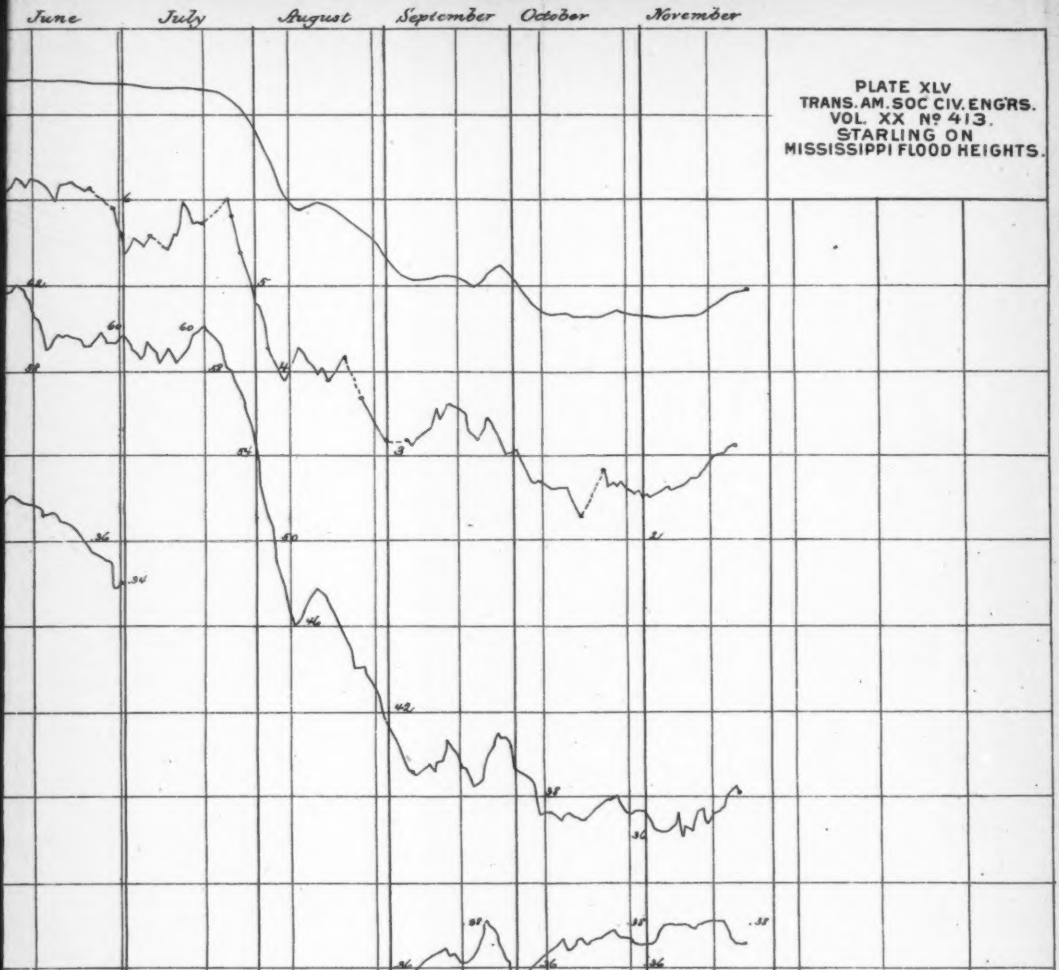
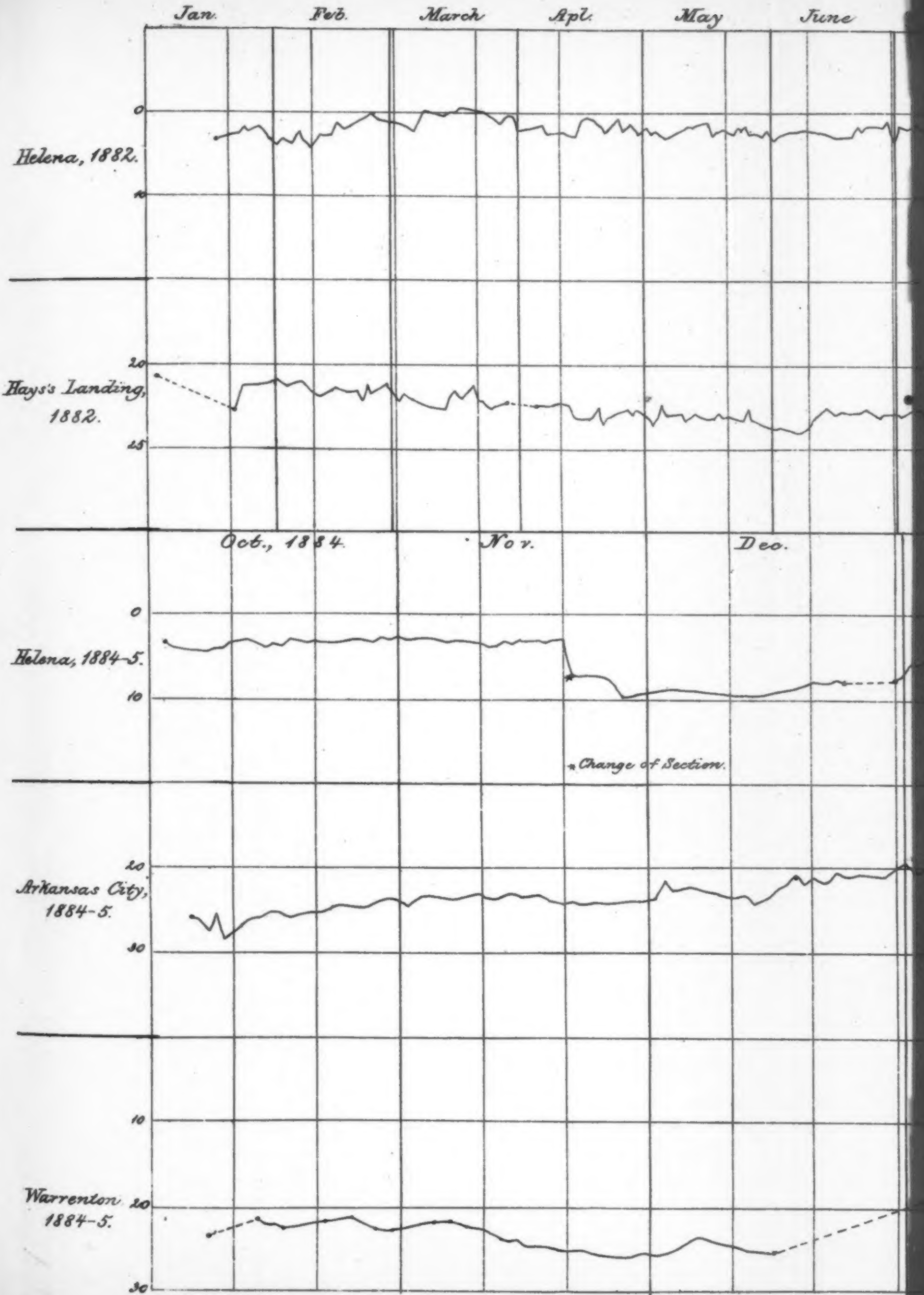


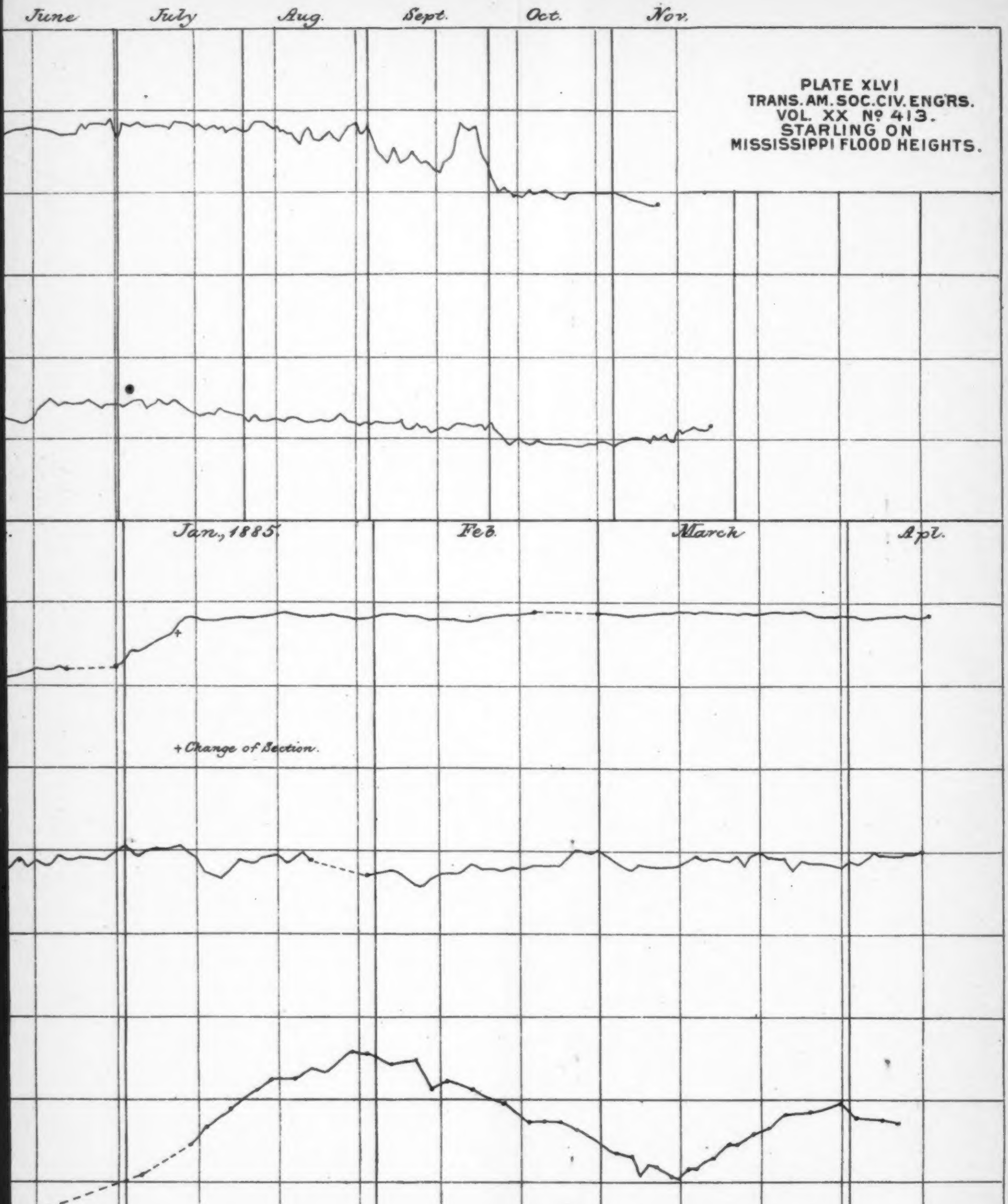
PLATE XLIV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX Nº 413.
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.
Skipwith's
Mayersville
Lake Providence
Point Lookout (opp. Hays's)
Arcadia
Duvall's
Brunswick
Vicksburg
Warrenton
Diamond Point
Moore's
New Town
Point Pleasant
Brooks's
Hard Times
115
110
105
100
90
80
70
530
540
550
560
570
580
590
600
610
620
630



January
February
March
April
May
June
Hydrograph
Velocity
Mean Depth
Slope Greenville-Hays's
Slope Hays's-Vicksburg


June
July
August
September
October
November
PLATE XLV
TRANS. AM. SOC CIV. ENGRS.
VOL. XX No. 413.
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.
Hays's Landing Observations of 1882.


Jan.
Feb.
March
Apl.
May
June
0
Helena, 1882.
10
20
Hays's Landing, 1882.
25
Oct., 1884.
Nov.
Dec.
0
Helena, 1884-5.
10
* Change of Section.
20
Arkansas City, 1884-5.
30
10
Warrenton 1884-5.
20
30



June
July
Aug.
Sept.
Oct.
Nov.
PLATE XLVI
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX No 413.
STARLING ON
MISSISSIPPI FLOOD HEIGHTS.
Jan., 1885.
Feb.
March
Apl.
+ Change of Section.
Showing Depth of Mean Bottom below Gauge-Zero.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

414.
(Vol. XX.—May, 1889.)

## DISCUSSION
ON
## IMPROVEMENT OF SEDIMENTARY RIVERS.*

By J. H. STRIEDINGER, M. Am. Soc. C. E., WILLIAM E. WORTHEN, Past President Am. Soc. C. E., and GEORGE H. HENSHAW.

J. H. STRIEDINGER, M. Am. Soc. C. E.—The regulating works chiefly used in the improvement of the Mississippi consist of:

Spur-dykes or wing-dams, and longitudinal or parallel dykes.

Although fascine structures of these types have been employed with success on the Rhine, Danube, Isar, etc., for many decades, in Germany such dams are now beginning to be discarded, the preference being given to a new kind of permeable dyke invented and introduced by Division Engineer (K. B. Bau-Amtmann) Wolf of Landshut, Bavaria.

This change from the methods hitherto used to the new system was caused by the favorable results obtained in the recent application of Wolf's dams on a reach of 44 miles of the lower part of the River Isar. There, in shallow and neglected sections of the river, Mr. Wolf drives single rows of piles parallel to, but some 12 feet outside of, the future permanent shore lines. Floating fascine mattresses attached to the piles, and pointing with their open, broom-like ends toward the old shore, form

* The Improvement of the Mississippi River, by William Starling. Transactions, Vol. XX, No. 406, March, 1889.

his permeable dams, the action of which is to increase the strength of the current in the river proper and to break the force of the stream toward the shore, thus causing erosion in the channel and deposit between the old and new shore lines.

When the river deposit reaches about the level of average low water, the top of this new foreshore is protected by fascines in the usual manner, and the floating mattresses, weighted by stones, are sunk to the bottom of the river, whence they revet the slope of the new river bank.

At points exposed to very strong currents two rows of piles are used, the second row being driven behind the first one and both united by stays.

In treating concave shores the dyke building gradually progresses in a down-stream direction.

The attempts to employ Wolf's permeable dykes as spur-dams have been abortive.

It is believed that, as on the Isar, the application of Wolf's system for regulating rivers abounding in shoals would also prove elsewhere a desirable innovation.

William E. Worthen, Past President Am. Soc. C. E.—The improvement of the Mississippi River for the purposes of navigation, and the security and maintenance of its banks, is a problem requiring the highest hydraulic talent; but it seems to me the great point is money for surveys and works, for which the appropriations have been too small and too fluctuating. It is impossible to work advantageously in this way, first on one basis, then on another, now with an appropriation, and now stopped for the want of one.

The project is of the largest interest to the Government on sanitary grounds, on political, the consolidation of State interest, and on economical, the security of property on its banks and enhancement of value. It should be under the obligations of the Government and should be met by generous and continuous appropriations.

Mr. George H. Henshaw.—The remarks of Colonel Craighill* embrace, so far as the author is aware, all that has yet been urged against the plan proposed. No attempt has been made to show any fault in principle or defect in design, but the assertion is simply made that the proposition to build dykes of brush or wattling is not a new one, and that such dykes have been tried for a number of years; meaning, of course, that the plan had already substantially been tried and failed.

Now, if this assertion was well founded, it would argue no little obtuseness in the author, because all the contrivances mentioned and a good many others had come under his observation and were carefully examined long before the paper was written; for which reason he feels

* Discussion on The Improvement of Channels in Sedimentary Rivers, by George H. Henshaw. Transactions, Vol. XX, March, 1889, p. 116.

confidently prepared not only to assert that the plan he proposes has never been anticipated by any published record, but to demonstrate that it differs radically, both in principle and design, from all the instances given by Colonel Craighill and others. This fact he had hoped was sufficiently shown in the paper itself, but the merely apparent similarity in the illustrations to certain dykes already tried seem to have led to the misconception in spite of the text.

Setting aside the "weed dykes" of Colonel Brownlow, there has no dyke of brush or wattling yet been tried in this country which had not for its object the direct diversion of the channel or the contraction of the water-way by the accumulation of sediment. The permeable or wattled dykes were especially designed for this latter purpose, and as long as they lasted proved very effective in many cases.

Now the author's plan is directly the reverse of this, or, to speak more accurately, has no action whatever of the kind, and does not depend for its efficiency upon contraction of the stream or compulsory diversion of the channel-way (the "supplementary structures" of course are not in the question). It is almost absurd to call the frail "fence" proposed a dyke at all. Beyond burying its base it is quite incapable of collecting sediment, and still more incapable of diverting a current. Its sole object, as stated in the paper, is to prevent erosion of the bottom outside the channel, and thus allow the latter to pursue one line of least resistance at all stages of the water.

But will so slight a barrier effect that purpose? or is it true, as the author has been told, that "when the Mississippi channel takes a notion to leave its bed nothing will stop it?"

Ever since the publication of the able and exhaustive work of Humphreys and Abbot, the author has, by experiment, observation and reading, sought to get at the true law governing the movement of sediment; and the invariable result of this study, he thinks, justifies him in the confident belief—First, that erosion, unobstructed, takes place not violently, but gradually, and in proportion to the friction on the surface. Second, that where erosion is greater than in that proportion it is due to the presence of obstruction to the current at the place where it occurs, the excess being in proportion to the horizontal resistance of the obstruction to the current. Third, when the obstruction is variable in its character, either by irregularity in structure (as in common permeable brush dams) or by oscillation (as in the use of separate trees, bunches of brush or grass anchored to the bottom, causing alternating, irregular volumes of water to pass through them), the erosion is also irregular and variable, and usually destructive.

The "fences" are, as has been said, designed to resist, not the current, but downward erosion; when their wattled meshes have covered their bases with sediment all practical resistance to the current ceases, except in regard to friction.

The truth of the three principles above stated, and the important deduction therefrom, shown practically in the homogeneous structure of the fences and their regular top line, is illustrated by the analogous action of snow blowing over low fences, of which the author has had extended opportunity of observation in Canada. It is invariably the case that snow drifted over a fence having a continuous top line deposits itself smoothly and evenly, while any irregularity produces a corresponding ridge or hollow ; he has frequently noticed a prominent ridge projected from such a fence where a post stood up above the top line or where a stone had been placed upon it. There appears to be no reason to suppose the action of sediment in water to be different from snow carried in the air; indeed it would seem to be far more certain in the first case than in the last, since the action of flowing water is steadier and more regular than that of wind.

The above remarks, it is trusted, will show that the "weed dykes" of Col. Brownlow, while they perhaps more nearly approach the author's idea than any of the other devices, have failed from their being an imperfect attempt to imitate what was incorrectly assumed to be nature, and also from their unfitness to adapt themselves to natural conditions and laws.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

# TRANSACTIONS.



415.
(Vol. XX.—June, 1889.)

# ADDRESS AT THE ANNUAL CONVENTION AT SEABRIGHT, N. J., JUNE 21ST, 1889.

By MAX J. BECKER, President Am. Soc. C. E.

The provision of the By-Laws of this Society which requires that its President shall deliver, at the Annual Convention, an address upon the progress of Engineering during the preceding year, has been observed by my predecessors in various ways.

While some of the former Presidents have confined themselves strictly to the constitutional provision, by general reviews of the professional progress and scientific advancement of the period; others have dwelt more in detail upon some specific subjects of particular interest at the time; and my immediate predecessor, most happily and appropriately, selected for his text a subject not only of absorbing interest to the profession, but at the same time of vast importance to the world at large; a subject no doubt as dear to him, as it was familiar, and of which he was most eminently qualified to speak, on account of his intimate relationship with the enterprise which furnished the substance for the discourse, to which we all listened with rapt attention—saddened only by the painful circumstances which compelled the author's absence and prevented the personal delivery of his address.

A rigidly literal compliance with the requirements of the By-Laws would of necessity gradually lead to a mere repetition of generalities, and the summarizing of facts already known; for the field of engineering science is now so large, and the development of its varied applications is so rapid, that an address, intended to cover the entire range, could only touch, in a general way, the leading points, and would have to dispose of the rest by a mere passing glance.

Moreover, the profession is rapidly dividing itself into specialties, and its members are finding abundant opportunities for satisfying their professional ambitions by mastering one of its various branches, instead of attempting to acquire proficiency in all.

The performance of this presidential duty is therefore becoming a more difficult task with each succeeding year, and as a justifiable compromise between a specific compliance with the By-Laws and what may be considered a pardonable departure from the prescribed practice, I trust I may be permitted, in this instance, to give you first a cursory glance of the field at large, and then confine myself more particularly to a review of the progress in that special part of the profession with which the long continued performance of my official duties has afforded me opportunities to become more familiar.

## Electrical Engineering.

Of all the forces of nature, the one which has remained a hidden mystery longer than all the rest, but which, of late, has distanced all in the rapidity of its development, and which is certainly destined to excel them all in the extended range of its useful applications, electricity, stands pre-eminent.

The startling phenomena of this subtle force, which once were witnessed only in fear and trembling, and whose harmless natural display spread terror and dismay among the awe-stricken beholders, are now counted among our sources of pleasure, and the very elements of their destructiveness are made subservient to our comfort and safety.

The adoption of electrical appliances for the useful purposes of daily life has of late become so extensive and general, that the limits of their practical application will undoubtedly be found, in the near future, to reach even beyond the most visionary fancies of the most sanguine enthusiasts.

By it we communicate with absent friends, regardless of distance or time; by it we regulate the movements of our traffic, sending messages from trains in motion and receiving replies thereto while speeding along at the rate of a mile to the minute; by it we converse orally at distances far apart; by it we light our dwellings and illuminate our streets, fire blasts, and explode mines; propel vehicles, print newspapers and operate machinery; disinfect sewers, weld metals, and execute criminals.

In the middle of the night we may, without raising the head from the pillow, by a mere touch of a tiny button, light the lamps, kindle a fire, awaken the servants, ring the burglar alarm, call up the fire department and summon the police patrol.

In the prosecution of subterranean or sub-aqueous operations, such as tunneling, mining, sinking of caissons, the use of electric light is found to be of special benefit; in its incandescent form it is absolutely safe against the dangers from explosive gases, and in caisson work it removes the risks and inconveniences incident to the ready and rapid combustion of inflammable substances under the influence of high atmospheric pressure.

While in ordinary cases the expenditure of this force depends entirely upon its simultaneous and continuously maintained generation, it has been found quite practicable to produce it in advance of consumption, store it for future use, regulate its expenditure, and consume it gradually as wanted; so that it may be manufactured, if desired, for a rising market, stored as stock on hand, and counted in the invoice with the available assets.

### Street Railways and Rapid Transit.

The rapid growth of our cities gradually forces the inhabitants to seek their homes in the suburbs and surrounding country, more or less distant from the business and manufacturing centers where their employment lies.

The desire for economy of time, and the necessity for punctuality and prompt attendance, have led to the introduction of various modes of conveyance, beginning with the street car tramways, propelled by horses, followed more recently by elevated railroads and cable car lines, and still more lately by the electric railroad, which latter system has, within a few years, developed much more rapidly than any of the preceding methods.

At the close of the past year, there were completed and in course of construction in this country eighty-five (85) electric railways, comprising about 450 miles of track, and the reports show that during the last year over eighteen millions (18 000 000) of passengers have been carried over these lines.

The cheapness of original construction and subsequent maintenance and operation commend their adoption in smaller cities, where the older systems would be out of the question ; and the practicability of their application in situations which would exclude cable lines and horse traction have led to their introduction in places like my own home, Allegheny City, where an electric railway is now in successful operation, which, in a distance of 1 mile out of, a total length of 4 miles, ascends, with a speed of fully 4 miles per hour, a hill over 400 feet high, upon gradients of 12½ per cent., with numerous curves of 40 feet radius, the cars being often loaded with seventy-five people.

Upon the lower portion of this line the electric current is supplied by means of an underground conduit, and on the upper portion of the line by the ordinary overhead conductors.

But while undoubtedly the electric railway will be generally preferred in the immediate future, it is by no means to be inferred that the cable lines are to be considered as the motors of the past. On the contrary, their use will not only be continued, but greatly extended wherever the conditions and circumstances favor their adoption. Among the advantages which they possess are uniformity of motion, generally satisfactory speed, and the ease with which in times of heavy travel the vehicles can be multiplied and combined into convoys; and the facilities which they afford to converging horse car lines, whose carriages they can attach to their own at the points of junction, saving thereby transfers to the passengers.

The machinery used at the power houses of some of the principal cable lines is of a very superior character, and some of the details employed are models of skill and ingenuity; noteworthy among these are the engines of the Brooklyn Bridge Cable Line, which many of us admired during the excursion at the time of the last Annual Meeting, and the original construction of which is very interestingly described in a recent contribution to our Transactions by Mr. Leverich, one of our Members, and at one time Secretary of this Society.

Elevated Railways, propelled by steam, must necessarily remain con-

fined to larger cities, where the volume of traffic promises a return for the capital invested in their expensive construction, and where the distances to be reached are sufficiently great to make the saving of time, by means of their superior speed, an inducement for patronage.

All these modes of conveyance are contributing to our comfort and convenience, and are of great benefit to mankind.

But in our appreciation of their great advantages, we should not forget the pleasures which are afforded to us by the numerous inclined planes of various types, upon which we are enabled to ascend mountains and reach commanding points of view otherwise wholly inaccessible, or too dangerous and difficult to climb.

To the lover of nature there is nothing more inspiring than the panoramic view of a picturesque landscape—be it a rocky mountain range or a gently undulating cultivated plain ; be it the fertile valley of a winding stream, teeming with busy industries and freighted with moving traffic ; or be it a lonely mountain lake resting in solitude amidst the shades of forest trees, far from the habitations of man.

Thousands of delighted tourists enjoy annually the magnificent prospect from the summit of Mount Washington over the White Mountain range of New Hampshire ; or view from the top of Lookout Mountain the glorious views of the Valley of the Tennessee and the historic cliffs where our heroes fought; or wait for the rising sun upon the plateau of Rigi Culm; or gaze from the smoking crater of Vesuvius upon the matchless picture of Naples' Bay, not to speak of the hundreds of thousands who seek the hill-tops of our cities, after the heat of summer days, to breathe the pure cool evening air and return to their homes refreshed in body and lighter of heart.

But how many of all these, do you think, will ever remember in their pleasurable sensations the engineer whose skill and ability has provided the means to enjoy them?

### WATER-WORKS.

The introduction of water-works is now so extensive in this country that there are but very few cities or towns of more than 5 000 inhabitants which are not supplied with one system or another.

The beneficial results upon the health of the populations are universally recognized, and the sanitary blessings and the advantages in point of comfort are beyond all calculation.

Wherever additions and changes become necessary in the older cities, wise precautions are generally taken under the advice and directions of professionally skilled experts, to profit by former lessons, and to avoid the errors of the past.

The most extensive enterprises now in progress in connection with water-works extensions are the improvements embracing the new lake tunnels at Chicago and Cleveland, the new Croton Aqueduct in the City of New York and the Aqueduct Extension in Washington, D. C. In all these cases the question of greater purity has been carefully considered in connection with the increased supply.

The collection and storing of water supplies for large cities and for manufacturing purposes, require, in many cases, the construction of extensive reservoirs with massive dams for the retaining of the reserve supply. The importance of constructing these dams of proper shape and size, and of suitable material and good workmanship, so as to insure their absolute strength, and give them sufficient resisting capacity against every possible contingency, has been taught by a recent lesson of frightful experience; and while the responsibility for this calamity may not be placed upon the shoulders of the profession, yet it will be well for its members to look upon it and remember it as a warning and an example.

An investigation of the cause of the failure of the South Fork Dam is now being made by a committee appointed under a recent resolution of this Society, who have just returned from a visit to the scene of the disaster.

Examinations and measurements of the structure and its surroundings, and extensive information obtained from various sources, will enable the committee to submit to the Society in due time a comprehensive statement of the conditions and circumstances which have induced and contributed to this most disastrous failure.

## Sanitary Engineering.

The extensions and improvements of the water supplies of our cities, naturally lead to the adoption of measures for the disposal of sewage.

The respective merits of the different methods employed for this purpose have been very ably presented to the profession, from time to time, in occasional contributions to our Transactions, by several members

of this Society, who stand pre-eminent in their special calling; so that, all that would now seem necessary in an emergency, is the exercise of sound and impartial judgment, in the adoption of the proper method for each special case.

The system most generally used in this country now, and which will no doubt be preferred for a long time to come, is that of common water carriage, by means of the so-called "Combined" plan of discharging all sewage and storm-water together through common outlets into adjacent rivers, lakes, or tidal waters.

The objectionable features of this method consist in the pollution of the streams and lakes, from which, in turn, the water supply may have to be drawn; and the injurious effects caused by the deposit and periodical exposure of offensive matter upon the shores of tidal waters.

In order to overcome—at least partially—these objectionable features, modifications of this method have been tried, consisting in a filtration and chemical purification of the sewage so as to reduce the offensive portions, and to render their final deposit into the streams of the district comparatively harmless.

The methods employed for some time at Pullman, Ill., and more recently at Orange, N. J., are examples of this system.

Under the provisions of a law passed by the Legislature of Massachusetts in 1886, the State Board of Health is authorized to investigate, through a commission of experts, the effect of sewage discharged into the streams and inland waters of the Commonwealth and to recommend to the courts annually plans in remedy of existing evils.

Acting upon the reports of this Board, several cities are now making preparations for the disposal of their sewage by various methods of purification and dilution.

In connection with some of these systems the fluid portion of the sewage is utilized as a fertilizer of farm land.

Judging from the very extended range of discussion following the papers of Messrs. Stearns and Allen, read before the Convention in 1887, the views of the members of the profession are very much at variance with each other, regarding the efficiency and economy of the different methods of sewage disposal, and the results of the numerous experiments made upon extensive scales in Europe are too conflicting to warrant us in drawing any general conclusions, or to justify us in the adoption of similar methods in this country at this time, without a very

exhaustive examination of all the conditions and circumstances governing each particular case.

By the general introduction of natural gas as a domestic fuel in Pittsburgh and other Western cities, a large amount of kitchen garbage and house sweepings, which heretofore were regularly burned with the solid fuel then in use, can no longer be disposed of in that way; and after various unsuccessful attempts to bury them, deposit them in the rivers, and burn them in open air, a number of specially designed furnaces were built for the destruction of these accumulations, to which are now added the offal from slaughter houses, the leached-out bark from tanneries and all garbage from the public markets. The heat created by the combustion of these waste substances is successfully utilized for generating steam in boilers attached to the furnaces, which, without the addition of any other fuel, except what is required for ignition, supply the motive power for operating the machinery in adjoining factories; so that these establishments not only improve the sanitary condition of the communities by the prompt and radical destruction of vegetable and animal refuse, otherwise liable to decay on our hands, but also furnish a cheap fuel supply for industrial purposes.

### Streets and Highways.

Nearly all the larger cities of this country have now passed the experimental stages of their street paving experiences, and have by this time entered upon a period of more permanent and substantial improvements in that department of municipal engineering.

The days of wooden roadways, the Nicholson, the cedar and locust blocks, will soon be remembered only as things of the past, like the plank roads of earlier date.

The various compounds, with which, at one time or another, nearly all our city streets have been plastered over and poulticed, have cracked and split, shrunk, melted and evaporated, and been carried off piecemeal, in course of time, by the persistent adhesion of their ill-flavored mixtures to the boot heels of the weary pedestrians in hot weather.

The abominable cobble stones, which have jarred our nerves and dislocated our spinal columns in years gone by, are finally relegated to the by-streets and back-alleys.

Such make-shifts may answer the purpose for a while in new towns of rapid growth, where better materials are not readily attainable, and

where the first cost is a paramount consideration; but they should never be renewed to the extent that has been the case so often, in spite of the most convincing experiences, and contrary to the best counsel of professional advisers.

The sums of money wasted in repeating these mistakes would, in many instances, have gone far towards carrying out much more permanent and substantial improvements.

For streets in the vicinity of freight stations or of manufacturing establishments employing heavy teaming; and for streets with steep gradients, pavements should be made of stone blocks or basalt, trap-rock, granite or hard limestone, laid upon a bed of broken stone ballast, topped off with sand or fine gravel, well rammed and joints filled with cement grouting or coal tar; for streets used by lighter traffic or carriages only, a well laid pavement of pure asphalt upon a bed of stone ballast answers the purpose very well, if prompt attention is given to the maintenance and necessary repairs; for parks and suburban pleasure drives a good macadamized road, well drained, and constantly kept in condition, affords a very superior and comfortable highway.

Of late years, pavements of hard-burnt fire-clay brick have been extensively laid in many cities and towns of the Middle States, where the supply of this material is very abundant and remarkably cheap. In some towns of West Virginia and eastern Ohio such pavements have been laid for less than a dollar per square yard; they make smooth roadways, are easily kept clean, and last very well under moderately heavy traffic.

This pavement is especially well adapted for cities of medium size, which cannot well afford more expensive kinds, and yet require something more substantial and durable than either asphalt or macadam.

But if there is one thing which needs reformation more than any other, it is the condition of our common county roads. If it is true that the highways of a people are a measure of its civilization, then we cannot complain if we are classed as an inferior type of low barbarians. The good nature with which we submit to the imposition of the annual road tax is only equalled by the sublime resignation with which we accept the result of the effort which swallowed up our money. Our Western members all know what is meant by "working the roads." It means to plow a furrow on each side, and scrape the mud into a ridge in the middle, simply to be washed down again into the ditches by the first

shower of rain. And this performance is repeated year after year, under the provisions of our statutes, and by the consent of a law-abiding but much-suffering people. During the spring and fall we struggle through the mud manfully, as best we can, and when winter comes, and the bottom literally drops out of the roads, we quietly compose ourselves and contentedly stay at home.

Some years ago, while out on an exploring expedition for a railroad in Southern Ohio, I was compelled to hibernate, so to speak, with my entire party for nearly a month in a lonely village among the hills of Wills Creek, in Noble County, and when I made an effort to advise my employers of our situation, I was cheered by the comforting assurance of the postmaster that my letter would certainly go out just as soon as the roads dried up.

A faint ray of hope, however, is just beginning to dawn in some parts of the country, most conspicuously in Ohio, where, under the provisions of a recent law, a number of free turnpikes are being built, of quite a superior character, by special tax levied upon the adjacent property.

The beneficial results of this wise system of improvements are very great and highly appreciated by the people, and it is sincerely to be hoped that other States will profit by the example.

## Canals and Hydraulic Engineering.

The days of ordinary canal navigation in the interior parts of this country may well be considered as numbered with the past. With the exception of the Erie Canal, which still maintains, to some extent, its character as a waterway of commerce, and excepting some parts of the canals in eastern Pennsylvania, New Jersey, Maryland, Ohio and Illinois, these primitive transportation lines have either been abandoned entirely, after outliving their short period of usefulness, or they are now merely utilized for carrying bulky products between local points, or for the supply of hydraulic power to manufacturing establishments.

The cargo displacement of an ordinary canal boat is 32 tons, which is just about equal to the carrying capacity of a modern railroad freight car. The canal boat moves during the open season at a speed of about 4 miles per hour; a railroad car travels all the year round, and at the rate of 25 miles per hour.

No wonder that out of 4 468 miles of canals built in the United States prior to 1840, at a cost of $214 000 000, 1 953 miles have been abandoned entirely, and the remaining portions have long ago ceased to be remunerative.

Considering the time when these works were built, and the limited practical experience of their projectors, they show even in their dilapidated condition many evidences of superior skill and good judgment, both in location and construction. Some of the old aqueducts on the western portion of the Pennsylvania Canal, which, in connection with the inclined planes over the Allegheny Mountains, constituted for many years a great highway of commerce, are even at this day, as ruins, graceful objects and picturesque features of the landscape.

The decline in the commerce of our inland canals has been followed, in a somewhat less marked degree, by a general reduction in the traffic upon our navigable rivers. If this reduction does not amount to a positive diminution, as compared with former periods, the results certainly show that there has been a relative reduction, when compared with the increase in population and the development of the tributary country. In view of the free navigation upon these rivers, and the generous and liberal efforts of the United States Government to maintain and improve their condition by expensive locks, dams and other methods, this decline, amidst the general progress and prosperity all around us, would be rather discouraging if it were not for the local benefits which the river traffic still confers upon the immediate inhabitants, by the cheap delivery of fuel and other articles of daily necessity in ordinary life. Still more discouraging are the immediate prospects for the various maritime canal projects.

The Panama Canal, upon which very large sums of money have been expended, has finally been abandoned after many unsuccessful efforts of its projectors to raise the funds still required for its completion, and after, as a last resort, modifying the original plans of a sea-level canal to one with locks. But notwithstanding this momentary failure, I most sincerely hope—and I honestly believe—that it is yet reserved for American engineering skill and American enterprise to resurrect and successfully carry forward this great and important project to its ultimate completion.

The Tehuantepec Ship Railway, which, for the purpose on hand, may properly be classed with the maritime canals, has not met thus far

with the encouragement which its importance and the unqualified endorsements of eminent professional talent would seem to justify.

Probably the sad fate of its Panama rival, which places it for the present out of the range of active competition, may assist in reviving the ship railway project to which our lamented fellow member, the late Captain Eads, devoted his energies during the last years of his useful life.

New interest is being manifested in the old Ship Canal project across the Isthmus of Nicaragua, which, in the matter of demonstrable feasibility, undoubtedly has many points in its favor.

The entire problem of inter-oceanic communication by way of the American Isthmus is presented in a very comprehensive report to the United States Navy Department by Lieutenant J. T. Sullivan: and the merits of the different canal routes have been made known to the profession through a contribution to our Transactions by A. G. Menocal, M. Am. Soc. C. E., and through the extensive and exceedingly interesting discussion of that paper by a large number of our members ten years ago.

Among other ship canal projects in active progress may be mentioned the Cape Cod Canal, which was commenced in 1880, and which will, when completed, connect the Bay of Cape Cod by way of Herring River with the head of Buzzard Bay in Massachusetts.

The magnificent success of the ship canal at Sault Ste. Marie, not only as an engineering project, but also as a commercial enterprise, has surpassed all expectations, and since its completion the traffic upon the Northern Lakes has been multiplied to such an extent that it has been found necessary to build an additional canal and a new lock of larger dimensions even than the one now in use.

The high tribute paid to this monument of American engineering skill by Mr. Samuel Keefer in his recently delivered annual address to the Canadian Society of Civil Engineers must certainly be very gratifying to the national pride and professional ambition of the engineers connected with this excellent work. The direct impulse given by the completion of this canal to the lake navigation and the indirect effect upon the general business of that region of country has stimulated the work on the hydraulic canal at Sault Ste. Marie, from which great results are expected, and it has also hastened the operations in progress for deepening and widening the channels through the shallow

parts of Hay Lake, whereby the route from Lake Huron to Lake Superior will be considerably shortened and generally improved.

A project is now being agitated contemplating a direct connection between Lake Superior and Lake Michigan across the narrow portion of the peninsula between Marquette and Escanaba, whereby the passage through the Sault Ste. Marie would be entirely avoided and much distance saved for the traffic between Lakes Superior and Michigan.

In the extension of the river walls in New York Harbor under the Department of Docks, large concrete blocks are being used, weighing from 60 to 75 tons, and requiring hoisting machinery of extraordinary size and power to place them in position.

Similar blocks are being placed in the walls along the lake front in Chicago, where they have been found to resist effectually the action of the waves in places where all former methods of protection have failed.

## Railroads.

Sixty years ago railroads were unknown in this country. At that time the population of the United States consisted of 12 000 000 of people. To-day we operate 160 000 miles of railroad and our population has increased to 60 000 000 of people.

In 1830 the aggregate wealth of the United States was less than $1 000 000 000. At present it is estimated at $56 000 000 000.

Just how much of this phenomenal prosperity may be due to the railroads, it is of course impossible to conjecture, but it may be safely assumed that they have very largely contributed to the result.

While the population has increased during the last fifty years about 350 per cent., the ratio of increase of the railroad mileage for the same period has been nearly four times that of the population; which would seem to indicate that they have not only supplied a want of the past, but have kept well up with the contemporaneous growth of the country, if they have not indeed advanced beyond its actual necessities.

The railroad mileage of the United States is now fully one-half that of the total railroad mileage upon this globe, while our population is only about one-twenty-fourth part, and our area of territory only about one-twentieth part of that of the inhabited world.

You have all heard the familiar illustration about girdling the equator a dozen times more or less with our railroad tracks; but it will no doubt

please you to know that since you heard this statement last, enough additional rail has been laid to give the equator another twist; and I might further supplement the illustration by the assurance that we have now a sufficient supply of materials in the tracks of this country to build a railroad to the moon.

Over these 160 000 miles of railroad we have carried last year 475 000 000 of people and transported 600 000 000 tons of freight. Upon these lines are engaged 1 000 000 employees. Their equipment consists of 30 000 locomotives, 21 000 passenger cars, 7 000 baggage cars, and 1 000 000 freight cars. The capital invested in their construction and equipment amounts to $8 000 000 000, and the yearly disbursements for labor and supplies exceed $600 000 000.

This, it must be admitted, is a marvelous showing for a period of three score years; sufficient to awake astonishment even in a country like ours, whose general growth and development have been on a most prodigious scale, and where everybody is so accustomed to gigantic results, that even the most startling statistics fail to create surprise.

The creation of these vast properties has been accomplished by aggregation rather than by preconcerted, systematic development.

The trunk lines of the present day are, to a great extent, composed of pieces of roads originally built by local enterprises, and absorbed, from time to time, by lease or purchase, to constitute, with other acquisitions, in connection with some specially constructed connecting links, the various systems under the management and control of the leading railroad companies of the country.

As may be readily imagined, the construction of our earlier railroads, as well as their management and operation, were conducted upon primitive principles, naturally conditioned by prevailing circumstances.

Although there are many notable exceptions, the locations of these earlier lines generally were made with very little appreciation of their immediate purpose, and less conception of their ultimate requirements. While some inferior lines, which have never developed into any importance, were located and constructed by engineers with exceedingly exalted ideas of their future possibilities, and upon a scale of extravagance even now inadmissible upon the best roads of the country, many others were built of such an inferior character as to make their future operations either permanent failures, or requiring large expendi-

tures for improvements, amounting, in many instances, to complete reconstruction.

Such refinements as equating the gradients upon curves, or adopting transition curves for easement at their terminals, or the introduction of vertical curves upon summits or in depressions, were rarely used.

Stone arches were built without reference to the laws of their stability; retaining walls were constructed without knowledge of the pressures they were expected to resist; and the wooden Howe Truss and McCollum Bridges were erected by their patentees upon the crudest designs and accepted in good faith without check or scrutiny. The only domestic literature then extant, giving information upon the general principles of bridge construction, was Squire Whipple's earlier treatise, and Herrman Haupt's book, published in 1851; but only a few of those engaged in the profession at that time were able to profit by their teachings.

The great majority of the engineers then in charge of these enterprises were men of limited professional attainments and of little practical experience.

The opportunities for acquiring a technical education and systematic practical training were few in number and on a contracted scale; and since there had been but very little need for engineers up to that time, the supply naturally corresponded with the demand.

But with the inauguration of the railroad era, engineers came into demand and the supply was forthcoming at once.

Scores of the ambitious youth of the country, with far more self-confidence and assurance than was warranted by their stock of knowledge, sallied forth with transits upon their shoulders, Henck's Field Book in their pockets, and an abiding faith in Providence to help them out in a pinch.

The tracks of some of the earlier roads were laid with so-called strap rail, being flat bars, spiked to longitudinal stringers, supported at intervals by cross timbers. The T rails which came into use soon after were all of iron and imported from abroad. They were of every conceivable pattern and shape, from 45 to 50 pounds weight per yard, and in lengths of from 15 to 18 feet. The fastenings at the joints were generally composed of small wrought-iron lip chairs; the cross-ties, although good timber was abundant and cheap, were rough hewn and ill shaped. Ballast was considered a luxury in which but few roads could afford to indulge.

Wooden trestling was used very extensively to save embankments and bridges, and the material employed in its construction was generally the rough hewn timber of the adjacent country, indifferently framed by unskillful men. The switches and frogs were constructed as if with the special object to have their presence distinctly felt in passing over them, and I can say from personal experience that they answered that purpose remarkably well.

Mean time the engineers who had charge of this kind of work literally earned their bread by the sweat of their brows. The young men of the present generation may think that the life of a railroad engineer is one of toil and trouble; but in the days of which I speak it was a life of hardship indeed.

Aside from the many privations in connection with their labor in the field, even their office work had to be performed under many disadvantages.

Such simple articles of common use as ruled profile paper and printed cross-section paper, continuous roll drawing paper and tracing cloth were unknown; the planimeter, the slide rule and calculating machine had not yet been invented; and the labor-saving operations by the various multiplying and reproduction processes by blue and black printing, hectograph and electric copying, stenography and typewriting, were not even dreamed of.

Just as soon as the overworked and underpaid engineer had finished his task and opened his road for traffic, his employment ceased, and he would leave the service, generally receiving in final settlement the worthless obligations of his insolvent employers.

The establishment of passenger and freight stations, repair shops, water and fuel stations, turn-tables, freight and transfer yards, was generally deferred until the development of the traffic indicated their want. The many ruins, hideous of design and monstrous of construction, which we still find scattered about in different parts of the country, date back to that transition period in the administration of railroads, when the duties of the engineer were performed by superintendents promoted from brakemen and general managers evolved from messenger boys.

In harmonious keeping with the track and road-bed, and with the stations and yard plans, was the motive power and rolling stock equipment, and the various fixtures and appliances pertaining thereto.

When the venerable and venerated Nestor of this Society, Past

President Horatio Allen, in his report to the South Carolina Railroad Company, in the year 1829, suggested "That the breed of horses could not be very materially improved, but that no one could foresee what the breed of locomotives would bring forth in the future," his prophetic vision could not have revealed what his own eyes have been spared to behold this day.

The gradual development from the "Stourbridge Lion," the "South Carolina," the "De Witt Clinton," and the various specimens of the so-called "Grasshopper Type" of locomotives of fifty years ago, to the creation of the magnificent passenger engines, the powerful consolidations and the ponderous decapods of our day, has been traced recently in such an attractive form by our fellow member, Mr. M. N. Forney, in one of the leading popular magazines, that it would be but a vain attempt on my part to interest you by anything I could add to the subject.

Not less marked is the growth from the primitive passenger wagons, resembling the once famous "Conestogas," to the gorgeous and luxurious parlor cars and sleeping coaches, furnished with every comfort of home life and equipped with every conceivable improvement of modern times.

The high state of perfection and general efficiency now attained in the operation of the better class of railroads in this country is due to the superior condition of their permanent way, brought about by a better construction of the lines recently built, as well as by the improved condition of the older lines; and also to the wonderful increase in the effectiveness of our motive power and the larger carrying capacity of our rolling stock.

The almost universal use of steel rail of larger size, held in proper alignment by strong and efficient splice joints, and secured on sharp curves by heavy braces, spiked thoroughly to sound hardwood ties, spaced closely together, and laid upon a thick bed of clean ballast, on a road-bed well drained, continuously fenced and carefully guarded at the crossings; together with the largely increased tractive power of our engines and the wonderfully enlarged capacity of our freight equipment, supplied with power brakes, rigid couplers, and protected by efficient signal appliances, ample station facilities and well disciplined employees, the whole managed by competent and scientifically trained officers; all these qualities combined make it possible to con-

duct the railroad service of the country with promptness and safety, and at exceedingly low rates of compensation.

Among the notable reformatory features of modern railroad progress in this country is the general tendency towards uniformity.

The broad gauges, originally adopted upon some of the roads controlled by English capital, have all disappeared; the narrow gauges are spreading out to the prevailing standard as fast as they can, the 5-feet Southern gauge is a thing of the past, and there now remains practically but one gauge with a varying limit of one-half of an inch.

The adoption of uniform standard time for the different sections of the country corresponding in longitudinal distance to one hour's difference in time, is universally recognized as a measure of great benefit in the operation of railroads throughout the country.

By the adoption of a uniform code of signals much confusion is avoided, and the accidents resulting from misunderstanding of signals are materially reduced.

The adoption of a uniform type of car couplers makes the application of power brakes on freight trains practicable; and while it admits of greater speed, it diminishes the liability to accidents by collisions and derailments, and prevents much personal injury to employees.

Through the persistent efforts of the Master Car Builders' Association uniform standards have been adopted in many of the details and minor appliances connected with the rolling stock equipment; all tending to simplify the shop work, and producing increased efficiency with a reduction of cost.

The gradual establishment of interlocking systems at railroad crossings, in depot yards and at junction points, affords not only increased security against collisions, but materially facilitates the rapid movement of traffic.

By a rigid observance of the Block Signal System rear collisions can be made virtually impossible, and by a judicious employment of electric safety signals at exposed and dangerous points, collisions can be effectually avoided even on single track lines.

The numerous accidents which happen at points where public highways cross the railroads at grade, in spite of alarm bells, watchmen and safety gates, have led to the enactment of laws in some of the Eastern States looking towards a gradual abandonment of existing crossings and the absolute prohibition of new ones in the future.

During the years 1887 and 1888 there were abolished in Connecticut ninety-three grade crossings at a cost of $625,000.

In Massachusetts a special committee of the Legislature has recently reported upon this subject, recommending that all dividend paying roads eliminate annually 5 per cent. and all non-dividend paying roads 2½ per cent. of their grade crossings at the joint expense of the railroads and communities, and that in future no grade crossings shall be permitted.

It is to be hoped that the beneficial results of these wise measures will induce other States to take this subject under serious consideration.

The most noteworthy engineering feature in connection with the general progress of railroad construction in this country is the building of bridge structures upon a constantly increasing scale.

In 1862 I triangulated the positions and laid the foundations for the piers of the channel span of the Ohio River bridge at Steubenville. This was the first iron railroad bridge over any of the navigable tributaries of the Mississippi River. The length of its channel span was 320 feet, and it was the longest iron truss ever attempted up to that time. It was designed by Mr. J. H. Linville, still a member of this society, and it has carried in safety and without accident the traffic of one of the principal Western connecting lines of the Pennsylvania Railroad for twenty-five years, and is now being replaced by Mr. Henry G. Morse, also a member of this Society, to make room for a double-track structure.

To-day twelve railroad bridges span the Ohio River between Pittsburgh and Cairo, and two more are in process of construction. There are fourteen railroad bridges over the Mississippi and fifteen over the Missouri. Many of these structures have spans of 500 feet, and one of the projected bridges over the lower Mississippi was designed with a span of 730 feet; but this plan, I understand, has been abandoned, and a cantilever structure adopted in its place.

The erection of these large bridges has become a special business in this country, and the leading contractors engaged in that pursuit have acquired wonderful skill in the performance of this dangerous and difficult work. Few people appreciate the risks and hardships encountered and the courage and judgment required in dismantling an old railroad bridge and erecting a new one in its place, with a deep and

rapid river running underneath, a strong wind blowing, and a hundred trains passing daily over the frail temporary supports, which must carry the traffic during the replacement.

The mere erection of entirely new structures free from the incumbrance of moving traffic is considered an easy job.

In October last the contractors engaged in the erection of the bridge at Cairo swung free and clear a 520-feet span in six days; and in November last the same parties erected the trusses of another span of 520 feet in forty-four hours, and more recently they erected a 400-feet span in thirty-one hours, the wind blowing a gale nearly all the time.

The successful completion during the past year of the Hudson River Cantilever Bridge at Poughkeepsie reflects great credit upon the builders and engineers in charge, and the equally successful completion and skillfully conducted erection of the Hawkesbury Bridge in New South Wales adds new fame to the same firm of contractors, whose leading partners are all prominent members of this Society.

Whether the limit of possibilities in bridge construction will be reached in the execution of Mr. Gustav Lindenthal's design of a railroad suspension bridge over the Hudson River, with a span of 2 800 feet, resting upon towers 500 feet high, and carrying, in addition to wagon-ways and foot-walks, six railroad tracks at a height of 150 feet above water; or whether the projected crossing of the British Channel will require still larger dimensions, are problems which may, perhaps, interest at some future day the younger members of this Society.

The recent revival of the temporarily abandoned Hudson River Tunnel project and the proposed tunnel under the river at Detroit are enterprises demanded by the necessities of continuous transportation lines for the through traffic of our railroads.

The efficiency attained under the admirable system of our modern railroad workshops is graphically illustrated by the recent erection of a locomotive in the Altoona shops of the Pennsylvania Railroad in sixteen hours and fifty minutes. Photographic views were taken at intervals, showing that at 7 o'clock in the morning the bare skeleton frame and cylinders rested upon wooden blocks and screw jacks. At noon the fire-box and boiler had been mounted. During the afternoon working hours the trucks and wheels were placed in position, the pilot attached and the cab erected. Work was stopped at 6 P. M. and resumed at

7 A.M. the next day, and at 2.50 P.M. the locomotive was completed and ready to start on its journey.

Aside from the important position which the railroads occupy in the commercial world, their beneficent influence upon the social relations of the community and their direct effect upon the advancement of civilization is universally admitted by all intelligent and right minded men.

The state of civilization of a country and the intellectual standard of its people are measured by the character of its national literature. If the same conditions apply to professional occupations, then the quality of our chosen pursuit, as it appeared half a century ago, was certainly not a very exalted one. At that time there was scarcely a sign of original American engineering literature in existence.

Our text books were translations from foreign authors even down to the elementary primers; and the few professional standards and treatises on special subjects were either imported or reprinted.

To-day the printing presses of our publishing houses are busy with the best productions of our native talent, and our professional periodicals are kept abundantly supplied with the current contributions of our brightest workers and deepest thinkers—while the selected transactions of our technical societies fill the book-cases of their members and furnish them volumes of valuable reference, all indicating the rapid march of our advancing civilization.

The condition of our Society is gratifying and its growth continues upon an increasing scale. Its high character is constantly enhanced by the admission of new members prepared for their professional duties by a thoroughly scientific training in schools conducted by eminently qualified teachers.

The high educational standard now attained by the successful students of our leading technical schools, not only places them upon an equal footing with the other learned professions in social life and business intercourse, but the services of the practicing engineers are at last beginning to command their merited reward.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

416.
(Vol. XX.—June, 1889.)

# SOME EXPERIMENTS ON THE STRENGTH OF BESSEMER STEEL BRIDGE COMPRESSION MEMBERS.

By JAMES G. DAGRON, M. Am. Soc. C. E.

## WITH DISCUSSION.

The use of steel in the construction of the Susquehanna River Bridge on the Philadelphia Branch of the Baltimore and Ohio Railroad, and the lack of data relative to the strength of full sized steel compression members, led to experiments which are the subject of this paper, and which were made by direction of the Chief Engineer.

The specifications for the steel to be used, in compression members for this bridge, were as follows:

"Steel used in compression members shall be open hearth, and shall not contain more than one-tenth ($\frac{1}{10}$) of one per cent. of phosphorus. A sample bar $\frac{3}{4}$ inch in diameter shall bend 180 degrees around its own diameter without showing crack or flaw, and when tested it shall have an ultimate strength of not less than 80 000 pounds

per square inch, and an elastic limit of not less than 50 000 pounds; and shall elongate at least fifteen (15) per cent. in eight (8) inches, and show a reduction of area of at least thirty (30) per cent. at point of fracture."

Although the specifications excluded Bessemer steel, it was afterwards decided to use it, and the columns were constructed of steel made by that process.

The steel used was made by the Pittsburgh Bessemer Steel Company, at their works at Homestead, near Pittsburgh, and was rolled by the Union Iron Mills, Pittsburgh.

The columns were constructed at the shops of the Keystone Bridge Company, Pittsburgh, contractors for the superstructure of this bridge.

The formulas specified for the allowable maximum stresses in steel compression members whose length exceeded sixteen times their least diameter, were as follows:

For posts with square bearings............... $\dfrac{11\,000}{1+\dfrac{l^2}{36\,000\,r^2}}$

For posts with one pin and one square bearing, $\dfrac{11\,000}{1+\dfrac{l^2}{24\,000\,r^2}}$

For posts with pin bearings.................. $\dfrac{11\,000}{1+\dfrac{l^2}{18\,000\,r^2}}$

$l$ representing the length of posts in inches, and $r$ the least radius of gyration of the section.

These formulas are an adaptation of Rankine's well known formula,

$$\frac{P}{S}=\frac{f}{1+\dfrac{al^2}{r^2}}$$

in which:

$P=$ Ultimate load in pounds producing the crushing or bending of the column.

$S=$ Sectional area of column in square inches.

$f=$ Constant, supposed to be equal to the ultimate resistance per square inch of a short column whose length is equal to its diameter.

$a=$ Constant, varying with the conditions of the end-bearings of the column.

In the present case the constant $f$ was assumed equal to 55 000 pounds instead of 40 000 which is generally used by American Engineers in the case of wrought-iron, and it was hoped that the results of the experiments would justify this assumption.

The columns tested were eight in number, of the following lengths between pin centers, viz., 16 feet, 20 feet, 24 feet and 25 feet $7\frac{1}{2}$ inches, two columns of each length being experimented upon.

The six shortest columns were made up, as follows:

| | | |
|---|---|---|
| 4 angles $2\frac{1}{4} \times 2\frac{1}{4} \times \frac{1}{4}$ inches....... | = 4.24 | square inches. |
| 2 plates $8 \times \frac{1}{4}$ inches ........... | = 4.00 | " |
| | 8.24 | |

The two longest columns were composed of the following sections:

| | | |
|---|---|---|
| 4 angles $2\frac{3}{4} \times 2\frac{3}{4} \times \frac{5}{16}$ inches...... | = 6.48 | square inches. |
| 2 plates $9 \times \frac{3}{8}$ inches........... | = 6.75 | " |
| | 13.23 | |

The rivets used were of soft steel, $\frac{5}{8}$ inch in diameter, and power-driven. The details of construction of the columns are shown on Plate No. XLVII.

The columns were crippled under pressure in a hydraulic press at the shops of the Keystone Bridge Company. In all the experiments the columns were placed horizontally in the press, without any intermediate guide or support, being counterbalancd at the center by one-half their weight. The pins in all cases were placed in a horizontal position. The pressure, which was recorded by a mercurial gauge, was applied by increments of about one thousand pounds per square inch of sectional area of the two largest columns, and of about fifteen hundred and seventy-five pounds per square inch of sectional area of the six smaller columns, and completely released between each application.

The vertical and horizontal deflection, and the compression of the column under each application of pressure, and its permanent deformation after each release, were carefully measured.

The apparatus used in measuring the compression is fully described in the paper on "The Strength of Wrought-Iron Columns," by Mr. G. Bouscaren, M. Am. Soc. C. E., Transactions, Vol. IX, page 449, and is shown on Plate XXIX accompanying that paper.

The steel made for the experimental columns was of the following chemical composition:

| | Carbon. | Manganese. | Phosphorus. |
|---|---|---|---|
| Blow 8845.......................... | .26 | .79 | .067 |
| Blow 8847.......................... | .27 | .83 | .067 |

and when tested in ¾-inch rounds rolled from a 4-inch ingot, it gave the following results:

| | Blow 8845. | | Blow 8847. | |
|---|---|---|---|---|
| Elastic Limit, in pounds per square inch | 51 190 | 53 890 | 53 140 | 53 150 |
| Ultimate Strength, " " " | 84 440 | 84 750 | 83 680 | 83 760 |
| Elongation in 8 inches, per cent | 18.75 | 18.75 | 20.75 | 20.2 |
| Reduction of area, per cent | 33.23 | 30.55 | 37.78 | 39.7 |

the fractures showing a fine grade of material. The test rounds were not annealed, and were tested in the condition in which they left the rolls. No tests were made on the finished material.

The photographs reproduced on Plates XLVIII and XLIX show the columns after failure, and the photographs reproduced on Plate L show, on a larger scale, the details of the points of failure of the columns.

The columns failed as follows:

No. 1. Failed by bending downwards at rivet in latticing, 1 foot 10½ inches from the center, buckling flange angles and web plate.

No. 2. Failed by bending upwards at rivet in latticing at center, buckling flange angles and web plate. One angle was fractured at point of buckling, and also at the two adjacent rivets in latticing.

No. 3. Failed by bending upwards between latticing, 3 feet from center, buckling flange angles and web plate.

No. 4. Failed by bending upwards between latticing, 4 inches from center, buckling flange angles and web plate.

The fracture in angle shown by photograph on Plate L was caused by handling subsequently to the testing.

No. 5. Failed by bending upwards between latticing, 9½ inches from center, buckling flange angles and web plate.

No. 6. Failed by bending upwards between latticing, 1 foot 5¾ inches from center, buckling flange angles and web plate.

No. 7. Failed by bending upwards at rivet in latticing, 3 inches from center, buckling flange angles and web plate.

No. 8. Failed by bending upwards at rivet in latticing, 1 foot from center, buckling flange angles and web plate.

In every case, after test, the rivets of each column were found, by hammer test, to be perfectly tight.

The results obtained are given by the accompanying table.

| DATE. | No. of column | Depth. Inches. | Sectional area. Square inches. | Length center to center pin-holes. | Ratio of length to radius of gyration. | Square of radius of gyration. | Ultimate Strength, in pounds per square inch. | Modulus of Elasticity. Pounds. |
|---|---|---|---|---|---|---|---|---|
| November 26th, 1884 | 1 | 8 | 8.24 | 16'0" | 42.05 | 20.86 | 41 020 | 27 705 000 |
| December 1st, " | 2 | 8 | 8.24 | 16'0" | 42.05 | 20.86 | 41 650 | 27 705 000 |
| " 4th, " | 3 | 8 | 8.24 | 20'0" | 52.564 | 20.86 | 39 440 | 26 113 000 |
| " 4th, " | 4 | 8 | 8.24 | 20' " | 52.564 | 20.86 | 41 650 | 25 816 000 |
| " 5th, " | 5 | 8 | 8.24 | 24'0" | 63.075 | 20.86 | 40 230 | 29 504 000 |
| " 5th, " | 6 | 8 | 8.24 | 24'0" | 63.075 | 20.86 | 40 070 | 28 398 000 |
| January 30th, 1885 | 7 | 9 | 13.23 | 25'7½" | 58.795 | 27.34 | 35 570 | 26 557 000 |
| " 30th, " | 8 | 9 | 13.23 | 25'7½" | 58.795 | 27.34 | 38 810 | 29 478 000 |

The comparison between the ultimate resistances obtained and those corresponding to the formula is given by the following table:

| No. of column. | Ultimate strength in pounds per square inch. | | Ratio of actual to calculated strength. |
|---|---|---|---|
| | Formula. | Actual. | |
| 1 | 50 080 | 41 020 | 81.90 |
| 2 | 50 080 | 41 650 | 83.16 |
| 3 | 47 680 | 39 440 | 82.50 |
| 4 | 47 680 | 41 650 | 87.34 |
| 5 | 45 050 | 40 230 | 89.30 |
| 6 | 45 050 | 40 070 | 88.95 |
| 7 | 44 960 | 35 570 | 79.11 |
| 8 | 44 960 | 38 810 | 86.32 |

The values of the constant $f$ derived from the experiments, are as follows:

| No. | $f =$ | | |
|---|---|---|---|
| 1 | 45 050 | | |
| 2 | 45 740 | | |
| 3 | 45 490 | | |
| 4 | 48 040 | | |
| 5 | 49 120 | | |
| 6 | 48 920 | Average ....... | = 47 060 |
| 7 | 43 510 | | |
| 8 | 47 480 | Average ....... | = 45 495 |
| | | General average | = 46 670 |

the general average for the eight columns being therefore 15.15 per cent. less than the value assumed for $f$ in the specification formulas.

The results obtained in these tests show that Rankine's formula cannot be used for steel columns in its present form, by simply allowing an increase of load of 37½ per cent. for steel over iron compression members. If this formula is to apply, new numerical co-efficients will have to be determined by a much greater range of experiments than those covered by the present paper, and it may then be found that in the law governing the flexure of steel columns of a given grade of material, increasing in length, the lateral stiffness of the material may become a factor of increasing importance in determining the stability of the column, as has been stated by Mr. James Christie, M. Am. Soc. C. E., in his valuable paper on "The Strength and Elasticity of Structural Steel," in Transactions, Vol. XIII, August, 1884.

These few experiments are laid before the Society in the hope that they may prove of some value to the profession, and also lead some of our

large steel manufacturing and bridge-building concerns to undertake a thorough series of investigations on the strength of full-sized steel compression members. The series of tests should embrace a certain number of columns of each length, with different grades of steel, increasing in carbon percentages, with constant manganese percentage, and low in phosphorus, so that it might be determined which grade of steel gives the best results consistent with safety. Such a series of experiments would no doubt result in a more general use of steel for structural purposes, as engineers would then be better able to properly proportion structures to be built of a metal whose one great advantage, aside from its increased strength, is that it permits the different parts of the structure to be built with different grades of material corresponding to the nature of the strains which occur in them.

## DISCUSSION.

James Christie, M. Am. Soc. C. E.—Experiments on the compression of solid bars of either iron or steel, having the same ratio of length to section (42 to 63) as the columns tested by Mr. Dagron, usually give results for maximum resistance at last equal to the elastic limit of the material, steel bars averaging 10 per cent., and iron bars about 25 per cent., above the elastic limit. The experiments of Mr. Dagron on built columns show a reduction of maximum resistance below the elastic limit of about 25 per cent.

The resistance of these columns was only from five to ten per cent. greater than we would expect from similar columns of iron having an elastic limit of 30 000 pounds.

Why these columns did not offer greater resistance, is a problem that may yield no more satisfactory solution than the extraordinary behavior of a material whose caprice under varying conditions still baffles the investigation of the patient observer.

C. L. Strobel, M. Am. Soc. C. E.—The above paper is of some interest to me, as the experiments described were made by the Keystone Bridge Company, whose engineer I was at the time.

The formulas for allowable stresses in steel compression members contained in the specifications for the Susquehanna River Bridge are correctly given by Mr. Dagron. These formulas are derived by the substitution of 11 000 for 8 000 pounds in the numerator of the formulas ordinarily used for iron compression members. In making this substitution, the authors of the specifications referred to did not expect, as Mr. Dagron implies, that the experiments would show an ultimate strength equal to five times the allowable stress given by the formulas. This relation does not exist in iron, and it was not expected in steel.

I mean to show that the tests made prove that the allowable stresses

as used give an ample margin for safety, and that in the light of these experiments no reduction in the stresses is called for.

At the outset it must be conceded that the results obtained do not fit the Rankine formula, but the results of tests on iron compression members for similar proportions of length to least radius of gyration agree no better with this formula.

The six columns of same section tested, varying in length from 42 to 63 radii, have an average ultimate strength of 40 700 pounds per square inch, from which the greatest variation of any one test is only 1 700 pounds, and this is for a column of medium length. The two longest columns vary only 500 and 700 pounds respectively from this average, having an ultimate strength that much less. These columns may, therefore, be said to have a constant ultimate strength for lengths up to 63 radii, which is a result that obtains in iron also for columns of the same proportions, as I have tried to show on other occasions.

Steel columns show a marked peculiarity in their behavior in the testing machine as compared with iron. When the stress is reached at which they fail, they give way quickly and apparently easily, by the bulging and buckling of the metal locally at some point. The explanation of this would seem to be that the metal flows readily and freely out of the line of stress as soon as the elastic limit is slightly exceeded. Steel is a homogeneous metal of granular structure and of uniform strength throughout. When the pressure has reached a limit which will produce a permanent change of form, it is clear that its molecules will rearrange themselves more easily and freely than is the case in wrought-iron, which is of fibrous composition and not of uniform structure or strength. The difference in the behavior of the two metals is very apparent to the eye. Wrought-iron yields slowly and stubbornly to the increased pressure and holds its form longer after the elastic limit is exceeded. When it yields, the damage to the metal is distributed over a greater area, or the member bends as a whole, and there is no local failure. In order to illustrate this behavior of steel, the photographs, Plate L, were made. The small confines and the peculiar contortions of the damaged part are clearly shown.

It would seem, therefore, that the ultimate strength obtained for these compression members is identical with their elastic limit. For the first six members this elastic limit, according to the tests, would be 40 700, and for the last two members it would be 37 200 per square inch average.

It is generally held that the factor of safety should be selected with reference to the elastic limit rather than the ultimate strength, and it will be admitted that the strength beyond the elastic limit is of less value in compression than in tension. The allowed stress, according to the specifications for the steel members under consideration, would be 9 010 to 10 020 pounds. The factor of safety with reference to the elastic limit, according to these experiments, would be 4.1 to 4.4. This is

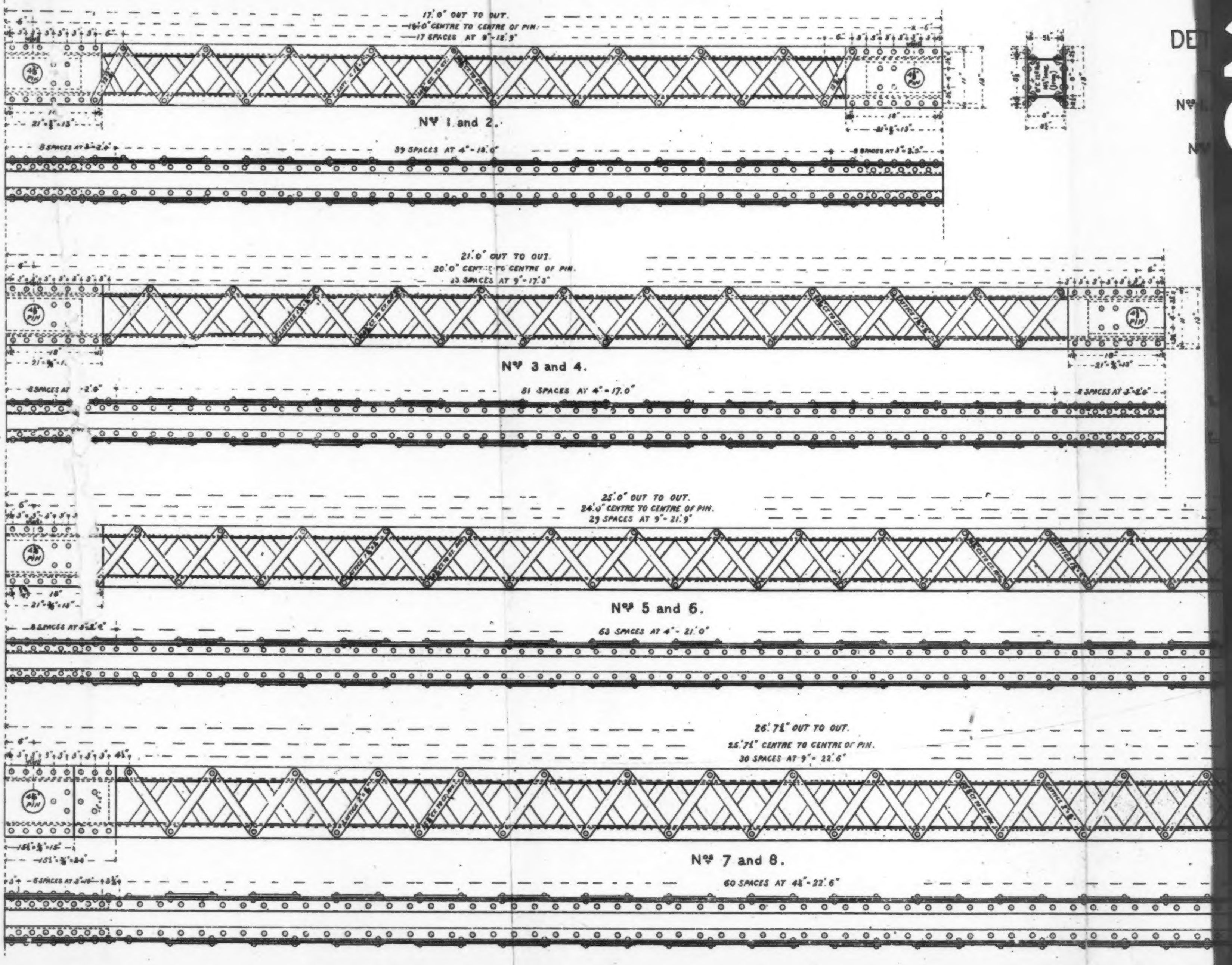
certainly a very ample provision for safety, more than would seem called for in a bridge for which the factor of safety, with reference to the elastic limit for iron tension members provided was, as usual, about $\frac{29000}{10000} = 2.9$, and the factor of safety, with reference to the ultimate strength, $\frac{46000}{10000} = 4.6$.

The conclusion which I deduce from these tests is not that we are straining steel in compression too high, but simply that steel columns in compression fail at their elastic limit.

JAMES G. DAGRON, M. Am. Soc. C. E. — In connection with Mr. Strobel's conclusions that these tests show that steel columns in compression fail at their elastic limit, it would be interesting to know what he means by their elastic limit. If the elastic limit for compression in short specimens is meant, and not the elastic limit for transverse stress, a considerable number of experiments made by different observers on wrought-iron and steel in compression have shown that in short specimens failing by compression, and not by bending or buckling, the elastic limit is almost the same as for tension; therefore in the present case, if this elastic limit is meant, the columns should have given an ultimate strength of about 50 000 pounds per square inch. If the elastic limit of the column as a whole is meant, this is a quantity which practically cannot be determined, as it is necessarily made up of the elastic limits of the different parts of the column, and in applying the stress during the test one of these parts may have its elastic limit reached before the other parts, and consequently will influence the elastic limit of the whole.

Whether the authors of the specifications for the Susquehanna River Bridge expected, or not, that the experiments would show an ultimate strength equal to five times the allowable stress given by the formulas, it is my recollection that after these tests were made, it was required by the Consulting and Chief Engineers of the Baltimore and Ohio Railroad that the sections of the steel compression members for that bridge should be revised, so that in no case would the allowable stress exceed 8 000 pounds per square inch, and I believe that they were revised by the Keystone Bridge Company in accordance with this requirement, which is about one-fifth of the average ultimate strength developed by these experiments.

Experiments made at Watertown Arsenal (see Ex. Doc. No. 12, 47th Cong., 1st Session) on 8-inch wrought-iron compression members of about the same sectional area as that of the 8-inch steel columns, which are the subject of this paper, and with ratios of lengths to radius of gyration varying from 53 to 66, gave an average ultimate strength of 34 400 pounds per square inch, which is within 15.48 per cent. of the average ultimate strength given by the 8-inch steel columns, and, therefore, a somewhat better result in favor of the steel columns than stated by Mr. Christie in his discussion.


17' 0" OUT TO OUT.
16' 0" CENTRE TO CENTRE OF PIN.
17 SPACES AT 9" - 12' 9"
No 1 and 2.
39 SPACES AT 4" - 13' 0"
21' 0" OUT TO OUT.
20' 0" CENTRE TO CENTRE OF PIN.
23 SPACES AT 9" - 17' 3"
No 3 and 4.
51 SPACES AT 4" - 17' 0"
25' 0" OUT TO OUT.
24' 0" CENTRE TO CENTRE OF PIN.
29 SPACES AT 9" - 21' 9"
Nos 5 and 6.
63 SPACES AT 4" - 21' 0"
26' 7½" OUT TO OUT.
25' 7½" CENTRE TO CENTRE OF PIN.
30 SPACES AT 9" - 22' 6"
Nos 7 and 8.
60 SPACES AT 4½" - 22' 6"

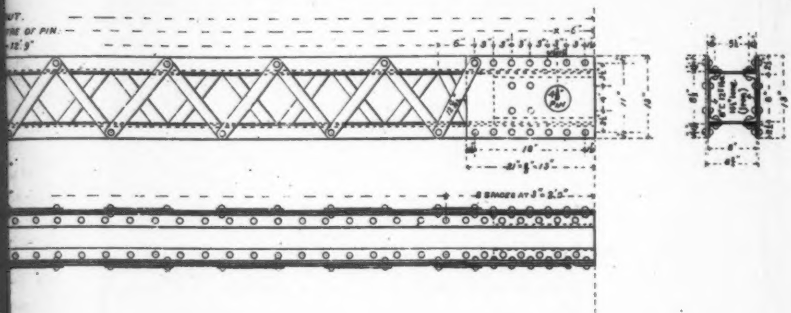
# DETAILS OF STEEL COLUMNS.

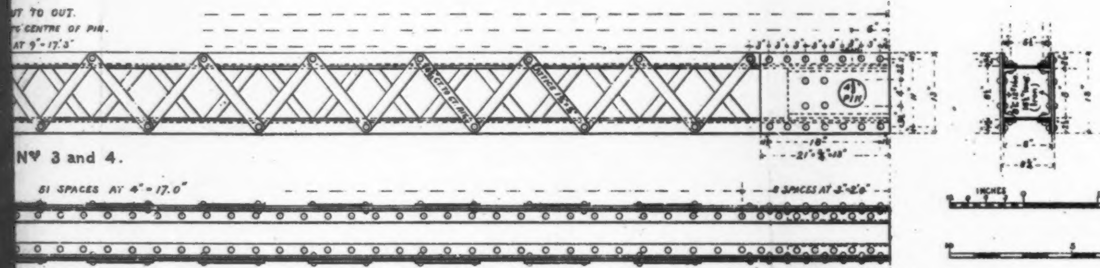
Nos 1, 2, 3, 4, 5 and 6. 8.24 sq. in. { 4 Angles $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$. 2 Plates $8'' \times \frac{1}{4}''$.

Nos 7 and 8. 13.23 sq. in. { 4 Angles $2\frac{3}{4}'' \times 2\frac{3}{4}'' \times \frac{5}{16}''$. 2 Plates $9'' \times \frac{5}{16}''$.

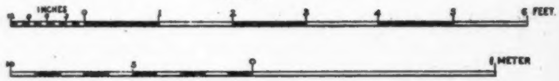
Rivets $\frac{5}{8}''$ diameter.

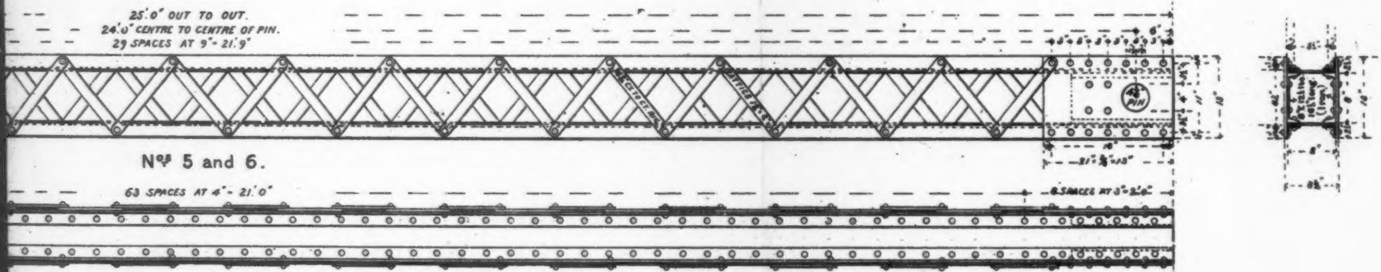
PLATE XLVII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX. No 416.
DAGRON ON STEEL
COMPRESSION MEMBERS.






SCALE.



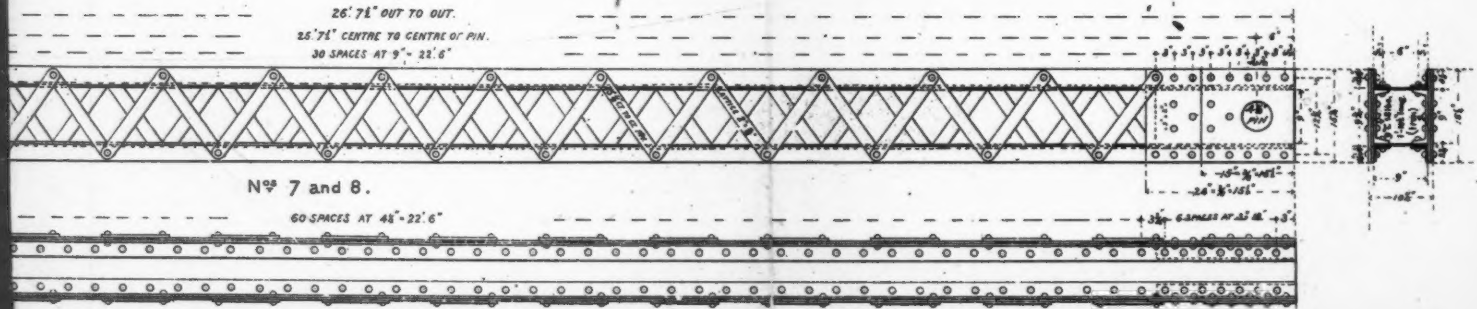
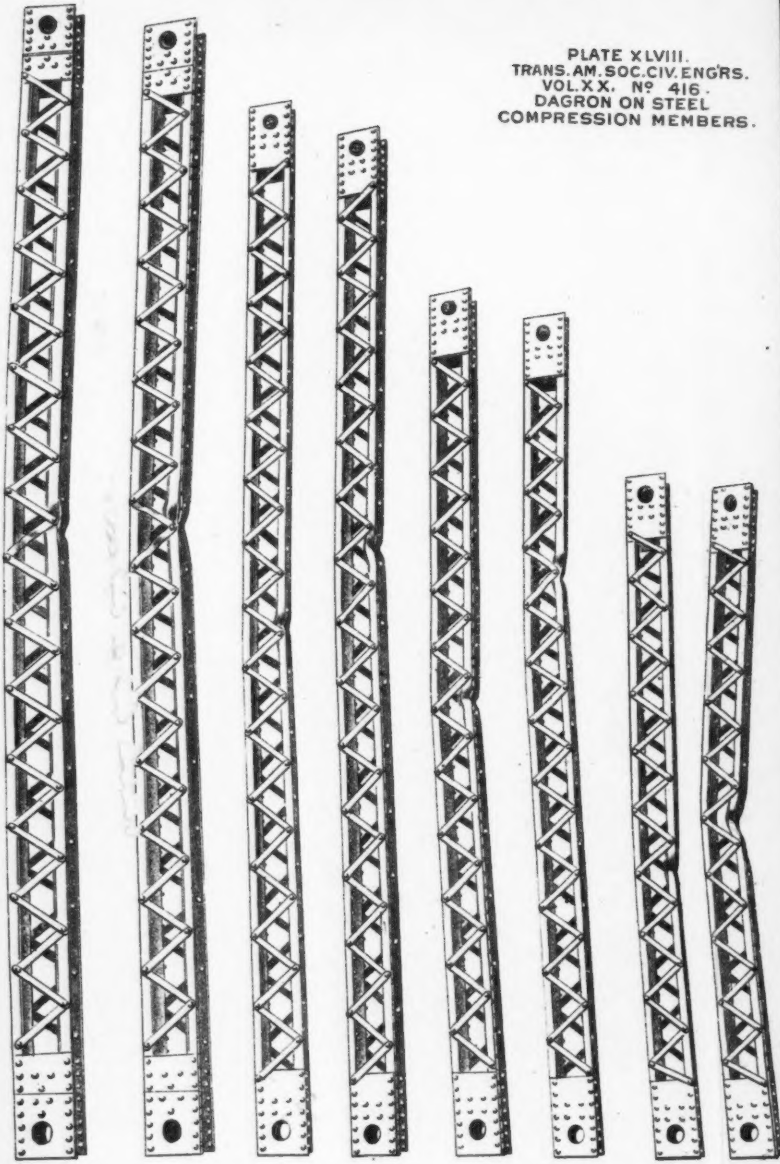
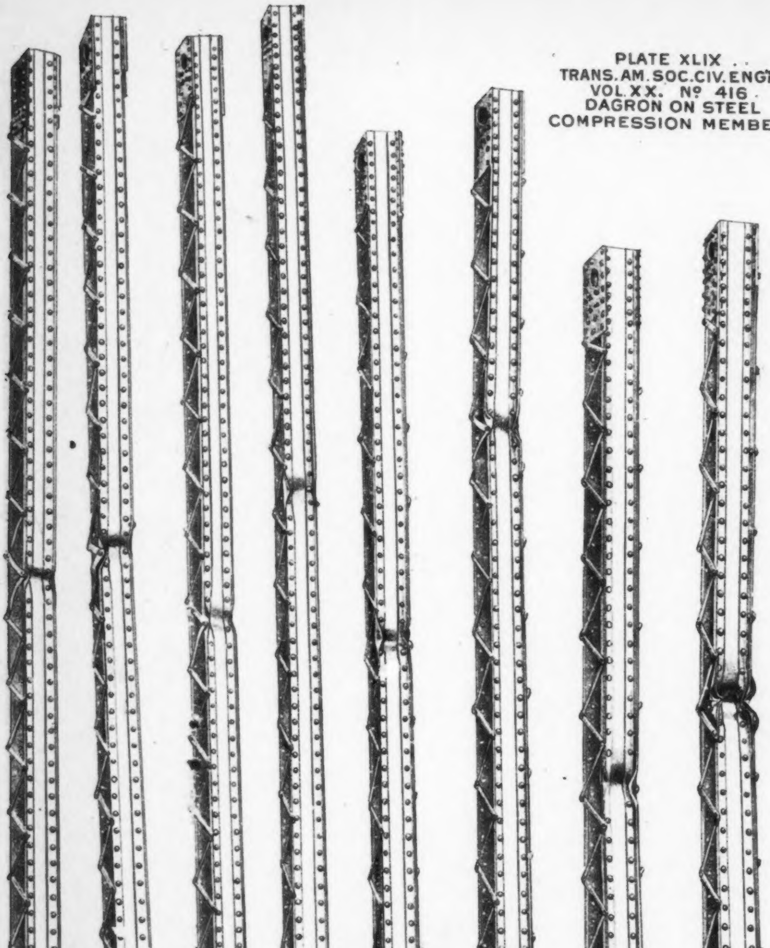



PLATE XLVIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX. No. 416.
DAGRON ON STEEL
COMPRESSION MEMBERS.



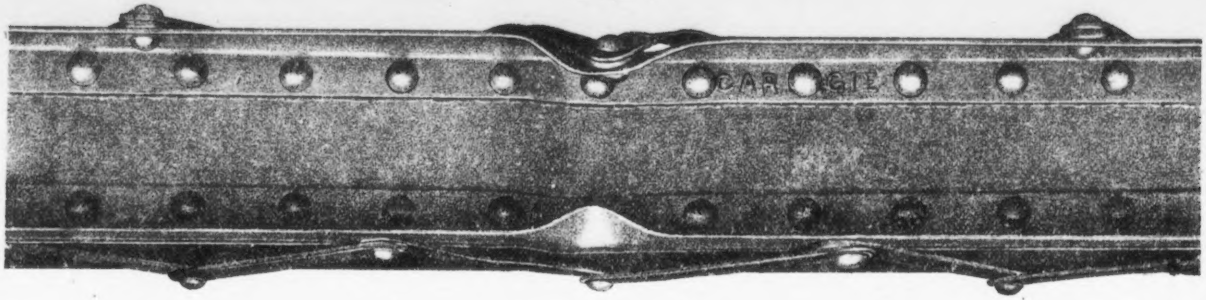
8. 7. 5. 6. 4. 3. 1. 2.

PLATE XLIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX. Nº 416.
DAGRON ON STEEL
COMPRESSION MEMBERS.



8. 7. 5. 6. 4. 3. 1 2.

Nº 1.

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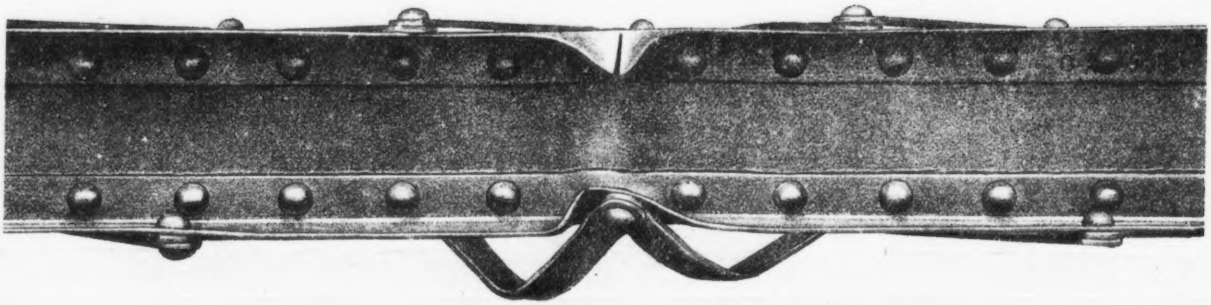

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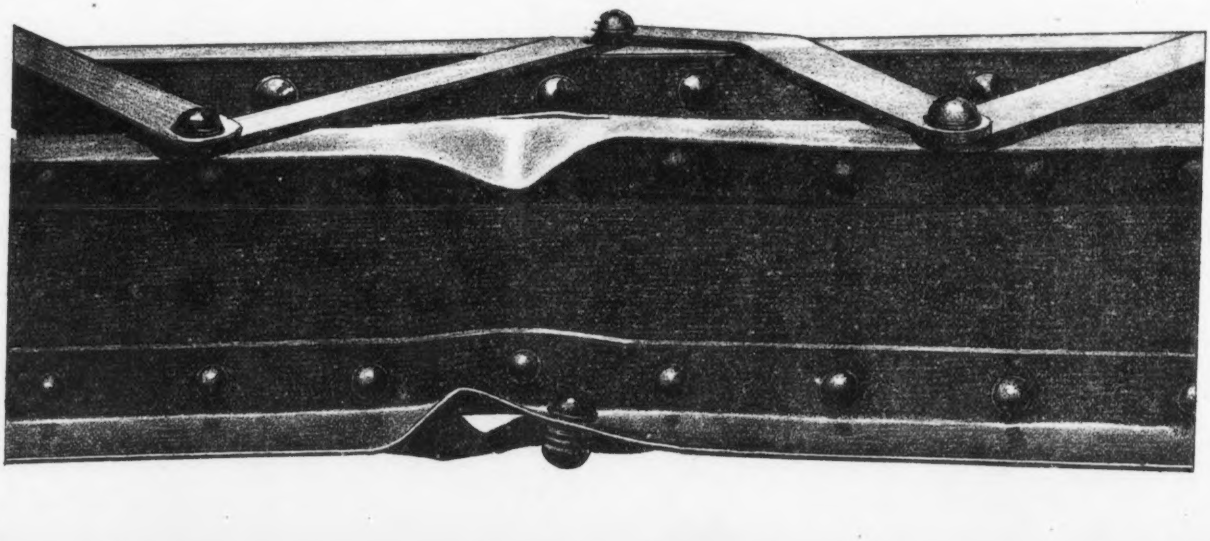

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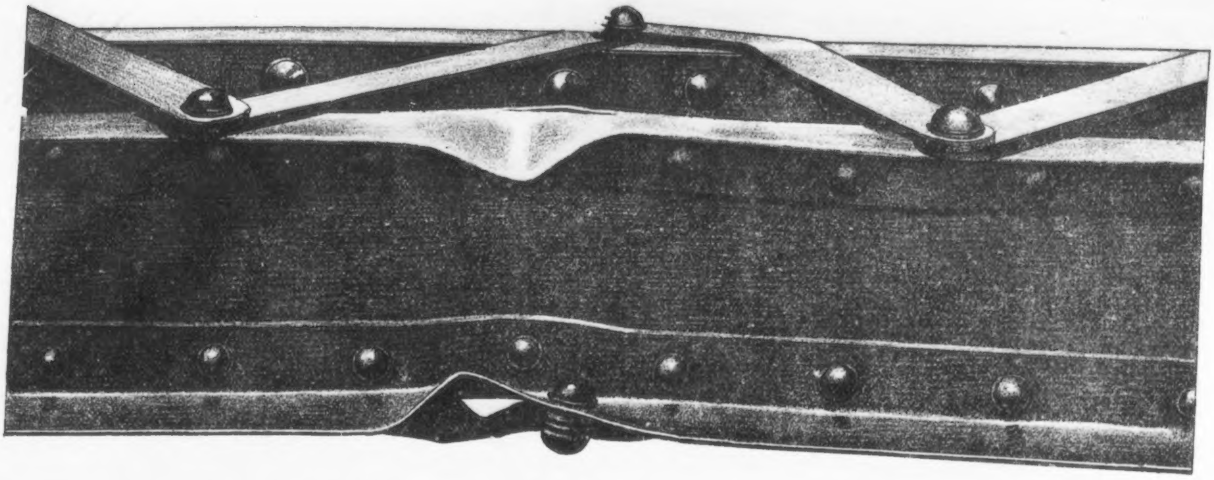
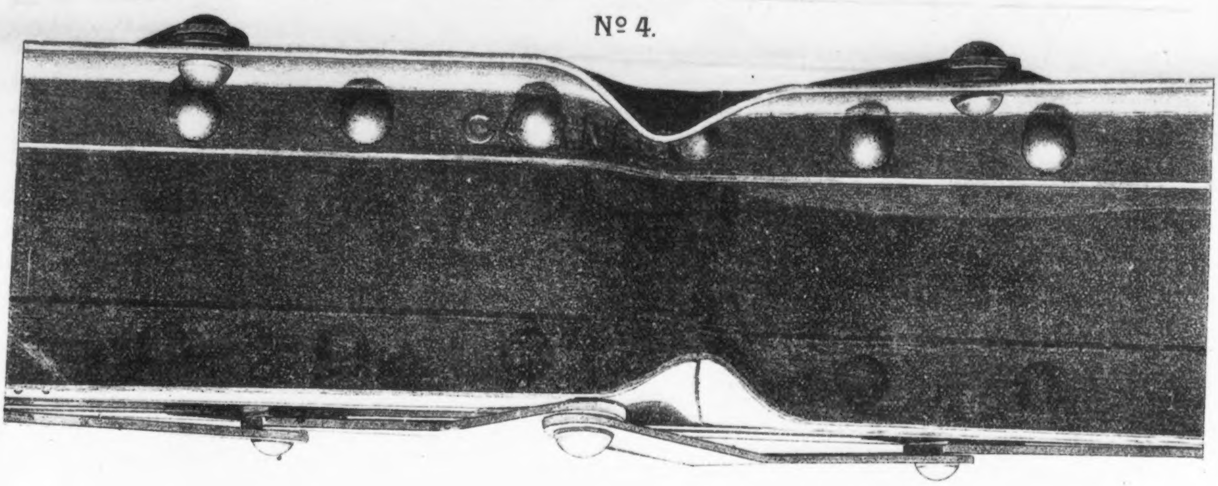
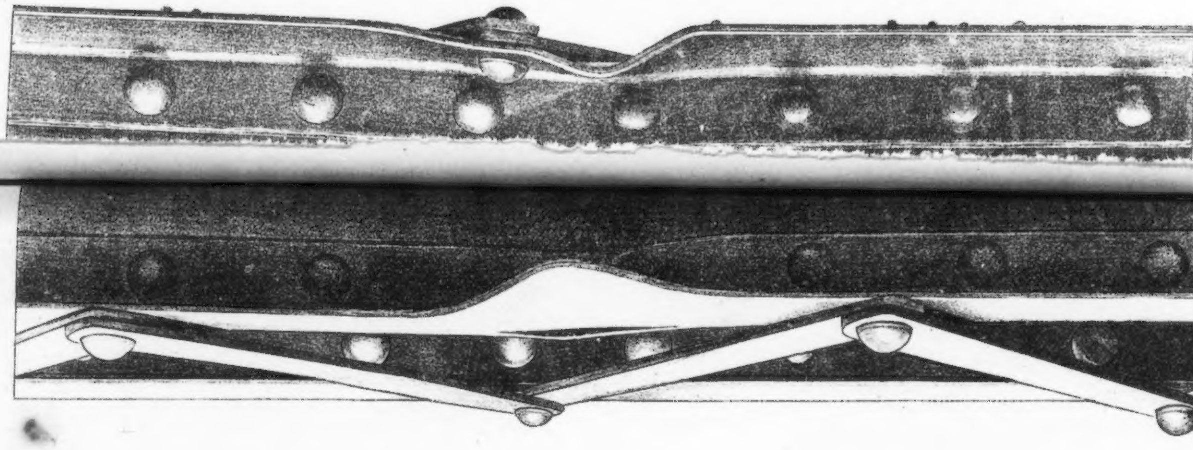


Nº 4.



Nº 5.



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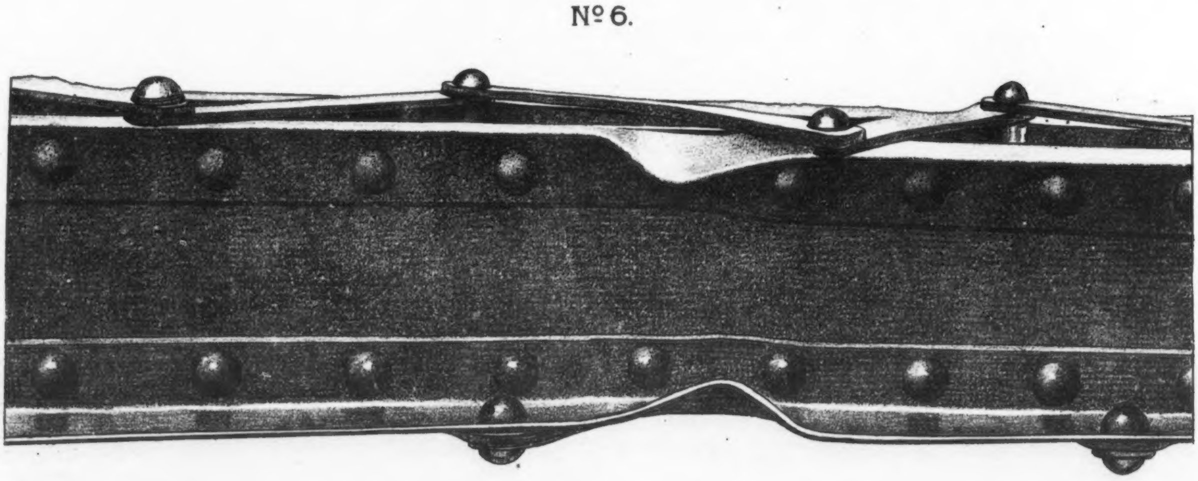


Nº 7.

Nº 7.

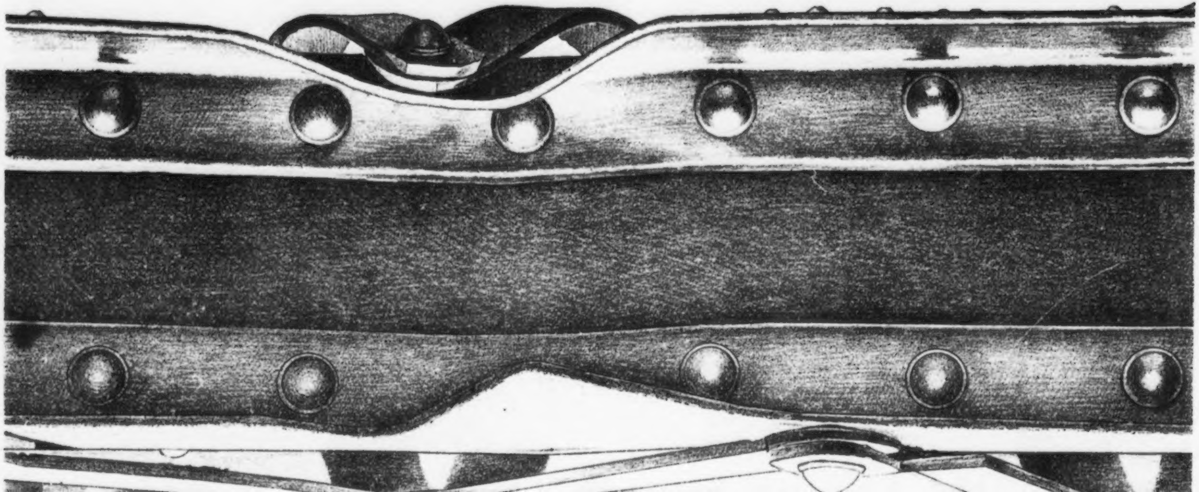
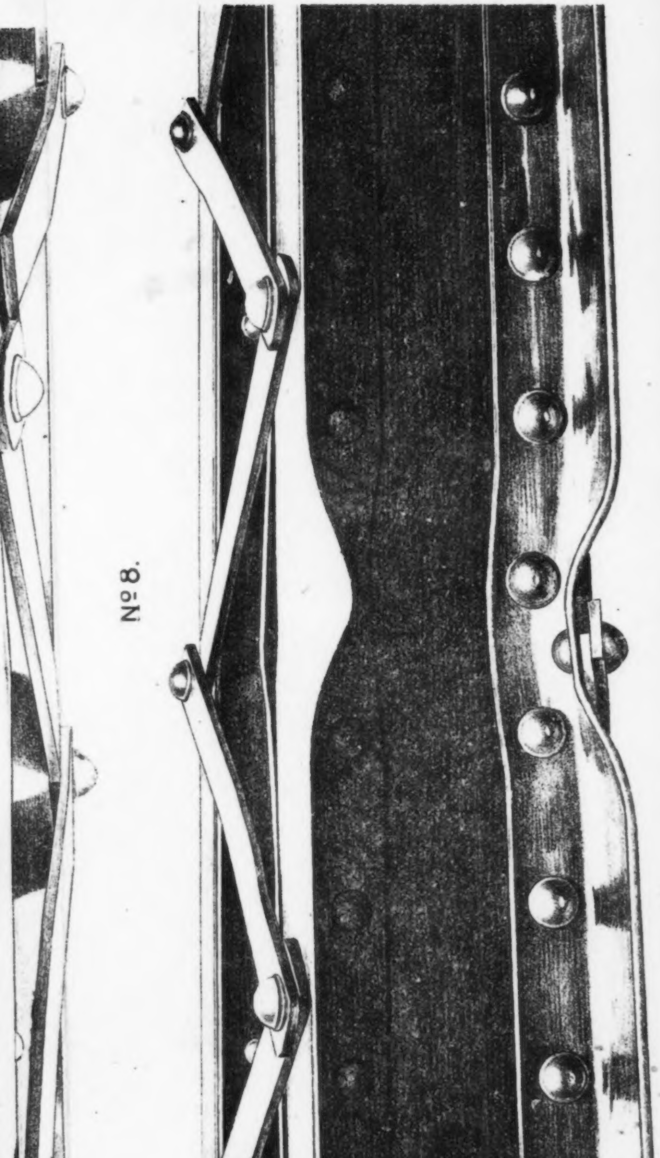


PLATE L.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX. No. 416
DAGRON ON STEEL
COMPRESSION MEMBERS.



No. 8.